eport No. FHWA/RD-80/167

IGHWAY ADVISORY RADIO SYSTEM ESIGN GUIDELINES

May 1981

Interim Report

Highway Advisory Radio Highlights

- Operates Under FCC TIS Docket 20509 on the Edge of AM Broadcast Band (530 KHz and 1610 KHz)
- Two System Configurations:
  - Cable Antenna System Confines Broadcast to the Roadway's Right of Way for a Distance of 1 Mile
  - Monopole Antenna System Whose Broadcast is Nondirectional and Provides at Least 2 Miles of Coverage Along the Roadway
- Provides Motorists with Real-Time Traffic Advisories on the Following:
  - Roadway Hazards and Incidents
  - Traffic Congestion
  - Travel Delays
  - Alternate Routing
  - Scenic Points of Interest

Document is available to the public through the National Technical Information Service, Springfield, Virginia 22161

Prepared for
FEDERAL HIGHWAY ADMINISTRATION
Offices of Research & Development
Traffic Systems Division
Washington, D.C. 20590

FOREWORD

This report presents the technical elements of Highway Advisory Radio (HAR) system design. The specific topics discussed include HAR reception; licensing restrictions; system design options, equipment, and performance; station and/or system cost tradeoffs; and a system design example. This report is directed toward engineers, system designers, and/or planners.

This report is being distributed to FHWA Headquarters, Regional, and Division offices, as well as to HAR equipment manufacturers and other interested researchers.

Other reports that may be of interest are listed below:

FHWA/RD-80/166	Highway Advisory Radio User's Guide
FHWA/RD-80/176	Systems Analysis and Design Guidelines for Highway Advisory Radio: Executive Summary
FHRA/RD-80/177	Systems Analysis and Design Guidelines for Highway Advisory Radio: Final Report
FHWA/RD-80/178	Mathematical Analysis of Electromagnetic Radiators for Highway Advisory Radio Volume I: Vertical Monopoles
FHWA/RD-80/179	Mathematical Analysis of Electromagnetic Radiators for Highway Advisory Radio Volume II: Cable Antennas

fr G D Love
Charles F. Scheffey
Director, Office of Research

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA/RD-080/167		

4. Title and Subtitle	5. Report Date
Highway Advisory Radio System Design Guidelines	May 1981
	6. Performing Organization Code
7. Author's)	8. Performing Organization Report No.
Howard C. Turnage	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
Atlantic Research Corporation 5390 Cherokee Avenue Alexandria, VA 22314	FCP 32L2-102
	11. Contract or Grant No. DOT-FH-11-9517
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	Guide book produced as a contract task item.
Offices of Research and Development Federal Highway Administration US Department of Transportation Washington, DC 20590	14. Sponsoring Agency Code T-0420

15. Supplementary Notes

FHWA Contract Manager: Warren F. Dorsey (HRS-32)
ARC Contributors: Michael Birdseye, Robert L. Hoover, Ann Muller & Dana Updyke.

16. Abstract

This report provides technical guidelines for the use of designers and planners of Highway Advisory Radio systems built in compliance with Section 90.272 of the FCC Rules and Regulations. An overview, description and backgrounf of HAR systems is given in the introduction. Possible users of HAR and a list of existing HAR installations is also included. Individual chapters are devoted to the subjects of FCC requirements and restrictions, factors affecting HAR reception, HAR system design options, HAR transmitters, monopole antennas, cable antennas, audio recorders and reproducers, telephone line interfacing, signing, audio message preparation, and HAR system costs. A design example is given using a system installed and operating in Gatlinburg, TN.

17. Key Words	18. Distribution Statement
Highway advisory radio; HAR; Travelers Information Station; TIS; monopole antennas; cable antennas; HAR transmitters; HAR modulation sources; HAR reception; advance visual signing; directional arrays; audio messages.	This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	175	

Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF FIGURES, continued

LIST OF FIGURES, continued

LIST OF FIGURES, continued

LIST OF TABLES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Overview

Basically a Highway Advisory Radio (HAR) system consists of a low-power AM transmitter (type accepted by the FCC), a cable or vertical monopole antenna, and a continuous-format tape recorder/playback unit. Typically, the AM transmitter is interconnected to the tape unit via leased telephone lines.

The critical component of the HAR station is its antenna. The antenna establishes the station's technical licensing requirements and coverage zone along the roadway as well as its capital and installation costs. Cable HAR stations radiate a tunnel-like broadcast zone that is concentrated along the cable and extends to a distance of 60 m normal to the cable. Vertical monopole HAR stations radiate an omnidirectional zone that extends radially from the antenna to a distance of 1.5 km. To minimize interference between HAR stations, cable HAR stations are recommended for metropolitan areas and vertical monopole HAR stations are recommended for rural areas.

Since the coverage zone of an HAR station is confined either to a specific roadway or several segments of roadways, several other factors require attention for an effective HAR installation. One of these is advance roadway signing. This is needed to inform the motorist of the HAR station, its frequency, and its expected zone of coverage. Currently, three advance visual signs are used--one 1.6 km in advance, one at the beginning, and one at the end of the broadcast zone. Another factor that requires attention is the

length of messages transmitted over HAR. Human factors research has found that audio messages should be received at least twice to insure motorist retention. By knowing this and the posted speed limit over the intended zone of coverage, a maximum message length can be determined.

Another key element requiring attention in HAR system design is the manner of obtaining surveillance data for the roadway(s) affected by the broadcast. Although several options are available (i.e., time-of-day data, construction schedules, helicopter surveillance, etc.) one of the most successful methods involves integrating HAR into a traffic surveillance and control network.

This report focuses on the following design aspects of HAR stations.

1. Station design configurations and options.
2. Station field strength requirements.
3. Station siting criteria.
4. Station broadcasting hardware and trade-offs.
5. Station advance visual signing recommendations.
6. Station design example.

Definition and Description

The term "Travelers Information Station" (TIS) is used to designate a licensed localized one-way radio service provided to the motoring public through the AM radios with which most motor vehicles are currently equipped. Application of TIS's to highway systems is referred to as Highway Advisory Radio. Since 1977 TIS's have been authorized in the United States for providing this service under rules that limit location, extent of coverage, and message content. TIS authorizations are limited to agencies of state and local governments. Messages may contain information on traffic hazards and travel

advisories, alternate routing, and local points of interest. However, commercial messages and advertising are prohibited. Because of the localized nature of the service, motorists must be notified by appropriate signing when approaching an area of HAR coverage in order that they may tune their radios to the proper frequency. However, despite the requirement for manual tuning, HAR does fulfill a need as has been demonstrated at numerous locations around the country where HAR systems have been implemented.

Background

The HAR concept (i.e utilizing standard AM broadcast receivers) was employed as early as 1940 on the George Washington Bridge between New Jersey and New York City. The system, developed by William S. Halstead for the Port Authority of New York and operated as a restricted radiation device under Part 15 of the FCC Rules, operated successfully during the summer of 1940 until the close of the New York World's Fair, which was the justification for its development.

In 1951 the Port Authority of New York installed a similar system in the Lincoln Tunnel. This system was unique in that it provided popular musical programs at all times except when advisory messages were being given. It remained in operation until 1955. It was discontinued because there was concern that radio signals might detonate blasting caps.

The well publicized Los Angeles International Airport advisory radio system was inaugurated in 1972. Licensed by the FCC in the Experimental Radio Service, it is the first licensed operation of its type to be authorized. Earlier systems operated under the restricted-radiation provisions of the FCC Rules, which require no authorization.

The present FCC Rules covering Travelers Information Stations resulted from activity initiated by the Federal Highway Administration (FHWA) and other interested government agencies in the early 1970's. An FCC/IRAC Ad Hoc Committee was formed to consider the requirements as set forth by FHWA, the US Park Service, and the US Forest Service. The result was a Proposed Rule Making (FCC Docket 20509) released in June 1975. The rule making attracted approximately 140 comments. About half of these came from representatives of the broadcasting industry which expressed itself as being greatly concerned about what many viewed as a competing service. In response to these concerns, the FCC deleted the somewhat ambiguous phrase "official notices and related communications" from the permissible message content, added a restriction prohibiting the identification of the commercial name of any business establishment (except trade names of carriers at air, train or bus terminals for purposes of announcing arrivals and departures) and placed strict limitations on permissible locations and zones of coverage. The FCC Report and Order establishing the new service was eventually released in June 1977. Under the present FCC Rules, TIS's can be licensed on 530 kHz and 1610 kHz. These frequencies, being just below and above the standard AM broadcast band of 540-1600 kHz, can be received at the edges of the tuning ranges of most AM radio receivers.

Current Applications

Current applications of HAR systems are discussed in "Highway Advisory Radio User's Guide," Federal Highway Administraiton Report No. FHWA-RD-80-166, Nov. 1980. A list of current HAR users (1980) may be found in Appendix A.

CHAPTER 2

FCC REQUIREMENTS AND RESTRICTIONS

General Restrictions on Interference

To prevent interference to, or competition with, the AM Broadcast Service, the FCC has placed a number of restrictions on HAR stations and operations. Separation distances are specified with respect to the protected contours of adjacent channel broadcast stations, but more important, HAR can only be authorized on a secondary noninterfering basis. This means that no harmful interference can be caused under any condition to any authorized primary stations (i.e. AM broadcast stations). Therefore, whenever interference conflicts occur between HAR and a primary station, the burden is on the HAR operator to make the necessary modifications. Failing to do so, he must shut down.

Restrictions on Location

To decrease the likelihood of interference to broadcast stations a number of specific location restrictions are written into the rules with which the HAR designer should be aware. The most significant restriction is that the Travelers Information Station must be located at least 15 kilometers outside the measured (calculated in the case of nondirectional stations) 0.5 mV/m daytime contour of any AM broadcast station operating on a first adjacent channel (540 kHz or 1600 kHz). The effect of this restriction is to exclude HAR from some areas, as may be observed from examination of Figures 1, 2 and 3. Figure 1 shows an approximation of areas from which HAR on 530 kHz is excluded.

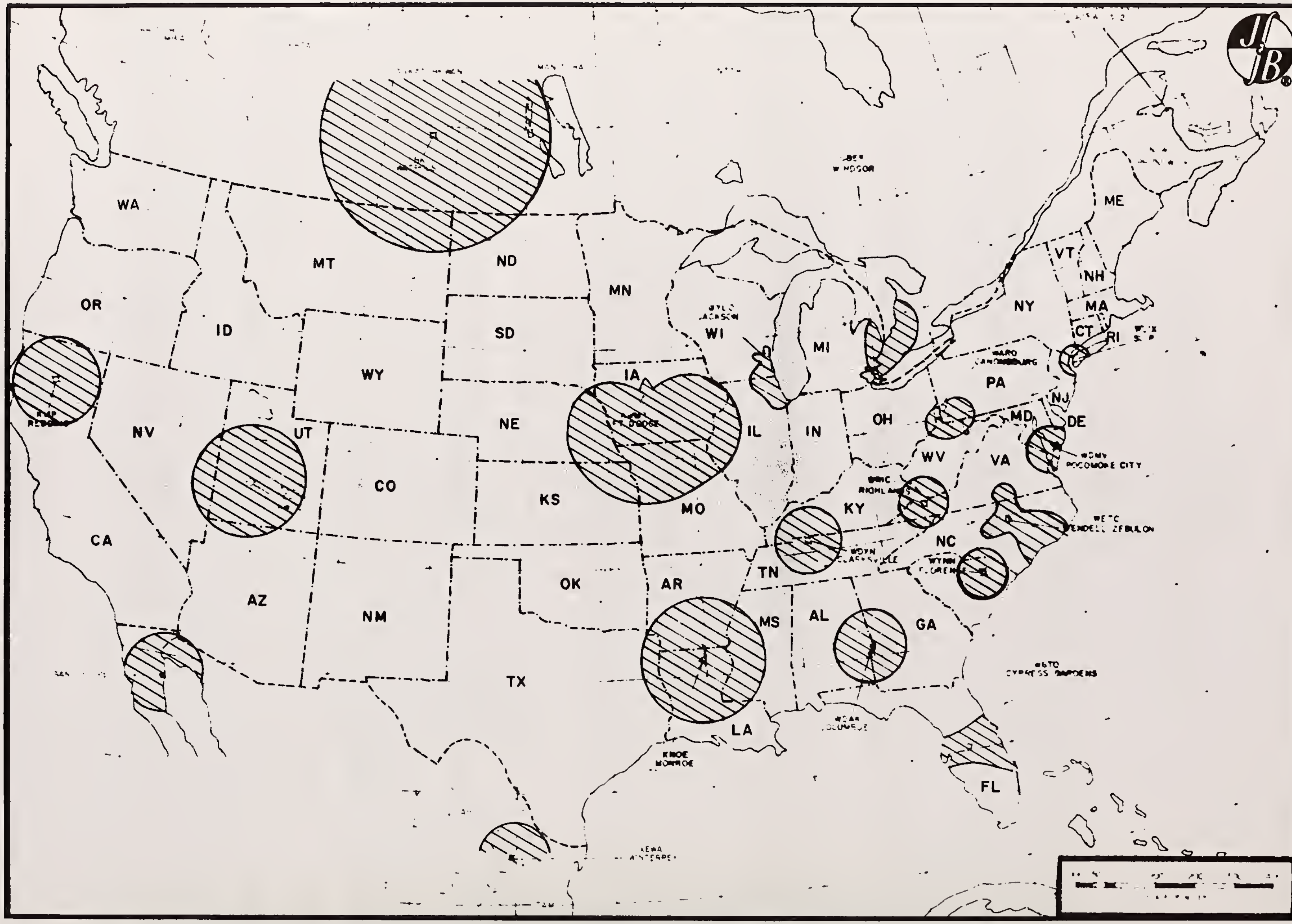


Figure 1. Areas Not Available to HAR on 530 kHz.

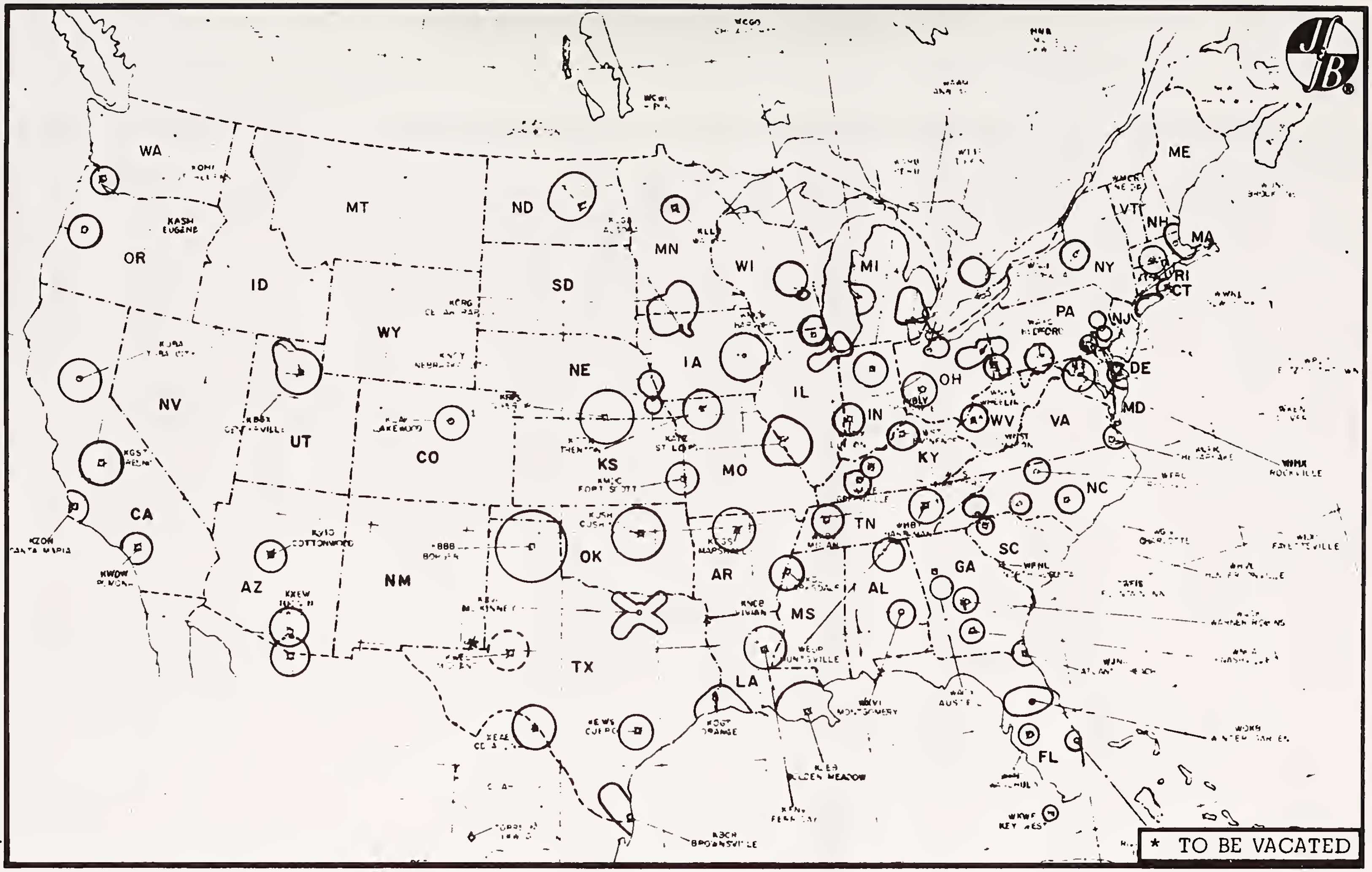


Figure 2. Areas Not Available to HAR on 1610 kHz.

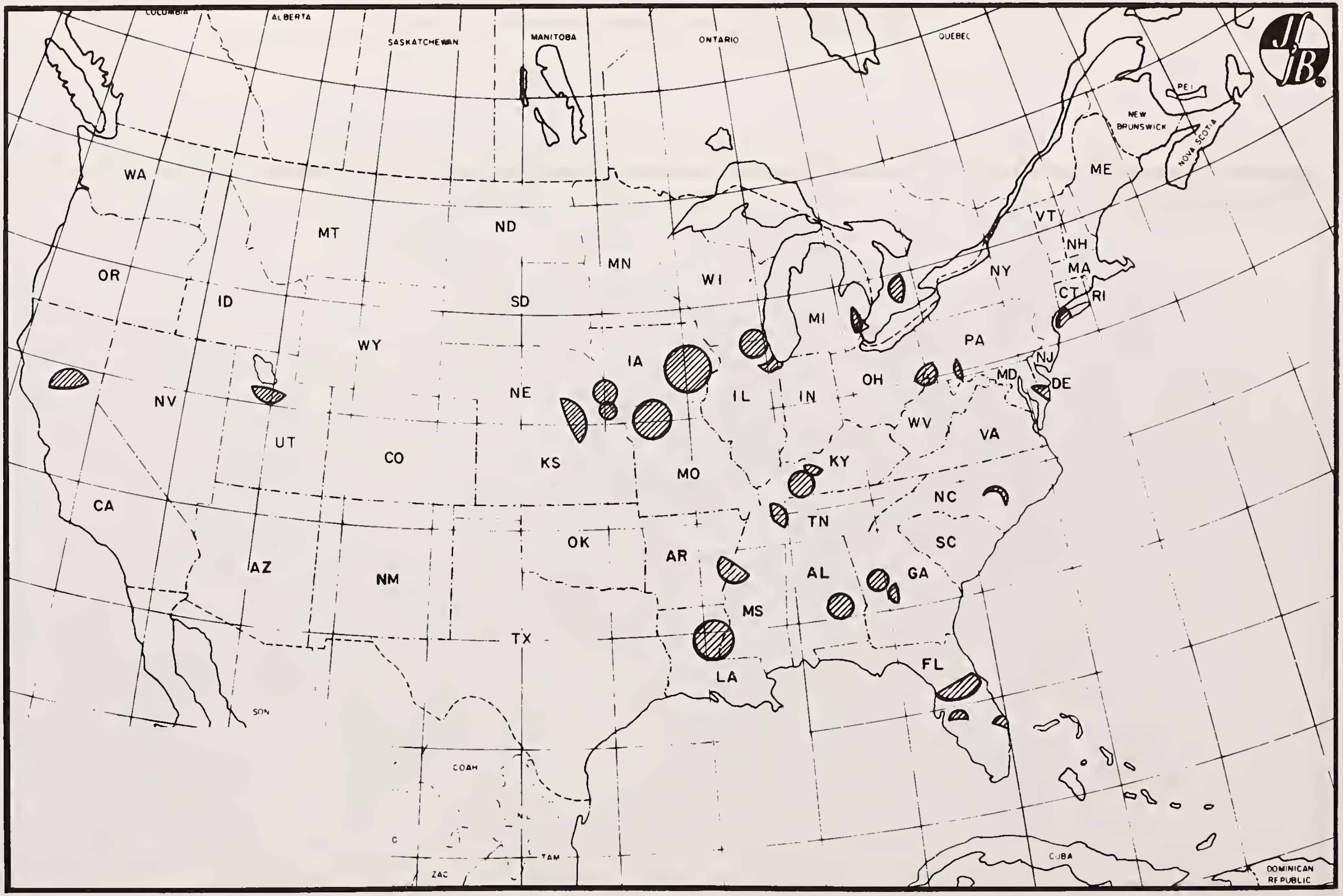


Figure 3. Areas Not Available to Licensed HAR.

Figure 2 shows those areas from which HAR on 1610 kHz is similarly excluded. Figure 3 shows where areas in Figures 1 and 2 overlap, giving areas where all licensed HAR operations are excluded.

A second restriction is that a HAR must be located far enough away from any AM station operating on the second adjacent channel (either 550 kHz or 1590 kHz) and on the third adjacent channel (either 560 kHz or 1580 kHz) to avoid cross-modulation and intermodulation interference in AM receivers tuned to the AM broadcast station's frequency. This is a less specific restriction requiring engineering judgement as to how much separation is really adequate. Some guidance can be obtained from the separation requirements imposed by the FCC on standard AM broadcast stations as given in section 73.37 (a) of the FCC rules. This section sets the following criteria with respect to the separations of a new station from stations already existing.

1. Stations separated by 20 kHz.
   a. The 2 mV/m contours of a new station may not overlap the 25 mV/m contours of an existing station.
   b. The 25 mV/m contour of a new station may not overlap the 2 mV/m contour of an existing station.
2. Stations separated by 30 kHz.
   The 25 mV/m contour of a new station may not overlap the 25 mV/m contour of an existing station.

Because of the low power of HAR stations, the 25 mV/m contour will be relatively small and close to the antenna site. Therefore, the above criteria will generally be met if the antenna site is located outside the 2 mV/m contour of stations offset by 20 kHz (second adjacent channels) and outside the

25 mV/m contour of stations offset by 30 kHz (third adjacent channels). If there are no second or third adjacent channels within 160 km or so, no further proof of non-interference is generally needed.

The only other FCC imposed location restriction is associated with the implied use of the station. Section 90.242 of the FCC Rules specifically states that locations "shall be restricted to the immediate vicinity of the following specified areas: air, train, and bus transportation terminals, public parks and historical sites, bridges, tunnels, and any intersection of a Federal Interstate Highway with any other Interstate, Federal, State, or local highway." An applicant for a HAR must be prepared to show in his application that the proposed station will be at one of these approved locations.

Restrictions on Message Content

HAR message content is restricted to "noncommercial voice information pertaining to traffic and road conditions, traffic hazard and travel advisories, directions, availability of lodging, rest stops and service stations, and descriptions of local points of interest."

Antenna Types Permitted

For HAR applications, the FCC permits "cable antennas" and "conventional radiating antennas (e.g., vertical monopole, directional array)". Different criteria are applied to the two antenna types. For cable antennas, the limitations are:

1. The length may not exceed 3.0 km.

2. Transmitter RF power may not exceed 50 watts.

3. The field strength of the emission may not exceed 2 mV/m when measured with a standard field strength meter at a distance of 60 m from any part of the station.

For conventional monopole antennas, the limitations are:

1. The antenna height above ground may not exceed 15 m.
2. Only vertical polarization of antennas is permitted.
3. Transmitter power output shall not exceed 10 watts.
4. The field strength of the emission may not exceed 2 mV/m when measured with a standard field strength meter at a distance of 1.5 km from the transmitting antenna system.

A licensee may be permitted more than one station in an area, each meeting the above criteria. Multiple stations would be justified, for example, when there is a need to cover more than one approach to a bridge, tunnel or air terminal.

CHAPTER 3

FACTORS AFFECTING HAR RECEPTION

Not all AM car radios respond equally to a given RF signal level. Variations in age, design and condition, as well as variations in external RF noise levels cause extreme variations in the minimum field strengths that can produce usable audio signals in different receivers in various noise environments. Because of this variation, it is useful to treat the problem statistically. That is, a certain specified field strength (expressed in millivolts per meter) will make it possible to communicate with a given percentage of passing cars (assuming driver cooperation). It will never be possible to reach 100% of the cars because less than 100% will have operable AM radios to start with. However, it is possible to design a HAR system to reach a substantial majority of those that pass within the intended reception zone.

AM Receiver Characteristics Affecting HAR Design

The major reason for selecting frequencies for HAR at the two extremes of the AM broadcast band is the almost universal availability of AM receivers in automobiles. Out of 885 respondents to a questionnaire used in a recent survey of cars using I-35W near Minneapolis, Minnesota, only 3% indicated that they had no AM radios in their cars. A survey of visitors to Yellowstone National Park made 5 years earlier (in 1973) disclosed that only 2% of 986 valid respondents had cars with no AM radio.

Despite the fact that most cars are equipped with AM radios not all receive 530 kHz and 1610 kHz equally well. Surveys in 1973 by Anderson and Robertson under an FHWA sponsored project gave the following results.

Survey I (345 cars)

70% would tune to 530 kHz

45% would tune to 1610 kHz

Survey II (54 cars)

80% would tune to 530 kHz

65% would tune to 1610 kHz.

The inability to tune all the way down to 530 kHz or up to 1610 kHz does not necessarily prevent reception of these frequencies. The receiver bandwidth normally extends the reception capbility to about 5 kHz on either side of the indicated carrier frequency. Realizing this, Anderson and Robertson also included a measurement of field strength required for what was judged to be satisfactory reception. For these tests the receiver was tuned to 530 and 1606 kHz, or if it would not reach either of these, then to the extreme low end or upper end of the band as appropriate. (Note: 1606 kHz was at that time considered a candidate for HAR). Results of the measurements at 530 kHz are shown in Figure 4. The results at 1606 kHz are not directly applicable to 1610 kHz and are therefore not included here. However, data at 1610 kHz on a random sample of 88 cars was taken by Dorsey and Pattakos in an inhouse FHWA survey during the summer of 1979. These measurements are shown in Figure 5. It is of interest to note that much higher field strengths are required at 1610 kHz than at 530 kHz to assure reception of a substantial percentage of the cars tested.

Although some of the preceding data was acquired in 1973 there is little reason to believe that it would be very different in 1980. Frequency synthesizer digitally tuned units are now available and may become more common in the future, but otherwise, basic AM receiver design has changed little since

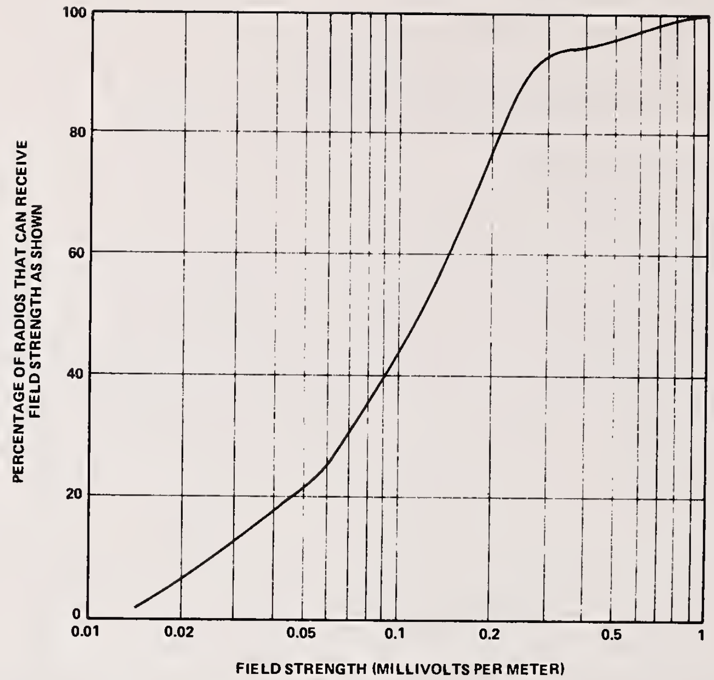


Figure 4. Cumulative Distribution of Automobile Receiver Sensitivity at 530 kHz (1973).

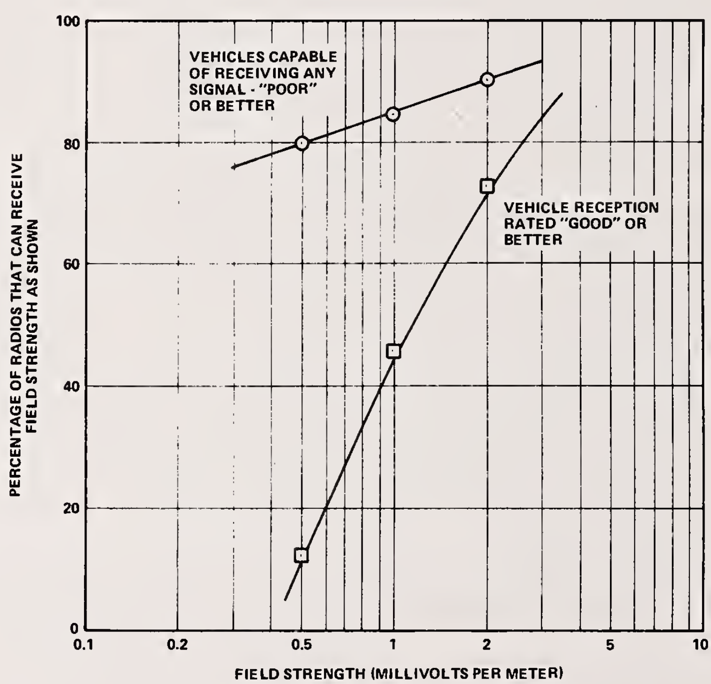


Figure 5. Automobile Reception Characteristics at 1610 kHz (1979).

industry conversion to all-solid state in the 1950's. Since HAR has become more widespread, the receiver industry has recognized its existence and indicated its intent to modify automobile receiver design to assure good reception on 530 and 1610 kHz. However, it will still take some time for the modified designs to dominate the population of AM auto receivers.

The Effect of External Electrical Noise

For any given AM receiver, the audio quality and clarity is directly affected by the ratio of signal strength to external electrical noise. The increase or decrease of external noise respectively increases or decreases the required signal field strength needed for usable reception. Four major sources of external noise are atmospheric galactic, man made and local automotive noise. Atmospheric noise, always present, is usually attributed to natural phenomena such as thunderstorms which may be occurring at various places on the earth's surface. Galactic noise originates outside the earth's atmosphere and, unlike atmospheric noise, is relatively constant throughout the daily and yearly cycles. Man made noise is the cumulative effect of electrical machinery, high voltage transmission lines, lighting systems, automotive ignition, etc., and is usually greatest in urban and industrial areas. Local automotive noise is perhaps a special case of man made noise, but deserves inclusion in a separate category because it is often the dominant noise source. It is the noise generated within the car in which the AM receiver is mounted, and includes the ignition system, windshield wiper motors, heat and air conditioning fan motors, etc.

Typical noise levels at 530 and 1610 kHz are shown in Table 1. The total noise intensity at a given time would be the square root of the sum of the squares (RSS) of all the contributing sources. Two items of particular interest in the table are (1) the high noise levels likely to be encountered on summer nights as compared to daylight hours, and (2) the large noise contribution of the automobile itself. The data shown in Figures 4 and 5 was in both cases taken during summer daylight hours in a suburban or residential area. Weather was for the most part fair and warm. Engines were running at idle, and at least in some cases (though not recorded) air conditioning fan motors must have been running. The electrical noise levels in the vicinity of each car radio antenna unquestionably varied widely from car to car (because of differences in the car's own noise sources) but may be estimated as follows:

	530/kHz (uV/m)	1610 kHz (uV/m)
Atmospheric	9	1
Galactic	0.6	0.6
Manmade, residential	7	5
Ignition	22	5
AC fan on low	10	5
RSS noise level	27	9

When engines are accelerated to highway speeds the ignition noise voltage approximately doubles. Typical conditions at highway speeds on a summer day with both heater/AC fan motors and windshield wiper motors operating on low speed settings are as follows:

Table 1. Typical Noise Levels at 530 and 1610 kHz, 7 kHz Bandwidth.

	530 kHz (μV/m)	1610 kHz (μV/m)
Atmospheric, Mid U.S.A.[a]		
Summer day (0800-1200)	9	1.1
Summer night (2000-2400)	74	32
Winter day (0800-1200)	0.1	<0.1
Winter night (2000-2400)	4	2.3
Galactic[a]	0.6	0.6
Man-Made[b]		
Urban	13	8
Residential	7	5
Rural	4	3
Automotive[c]		
Ignition, range of measurements, engines idling	14 to 37	10 to 11
Ignition, RMS value, 6 cars	22	<10
Heater/AC fan motor, range of measurement	<10 to 75	<10 to 40
Windshield wiper motor, range of measurement	25 to 65	up to 10

[a] From World Distribution and characteristics of Radio Noise, CCIR Report 322.

[b] From Man Made Radio Noise, CCIR Report 258-2.

[c] Measurements made with standard field strength meter on engine hood near radio antenna location. Measurements made on 6 cars, four with 8 cylinders and two with 4 cylinders.

	530 kHz (uV/m)	1610 kHz (uV/m)
Atmospheric	9	1
Galactic	0.6	0.6
Manmade, residential	7	5
Ignition	44	10
AC fan on low	10	5
Windshield wiper	25	5
RSS noise level	52	13

If the above process is repeated for a summer night (atmospheric noise up to 74 uV/m and 32 uV/m respectively for 530 and 1610 kHz), the results are:

Frequency	RSS Noise Level
530 kHz	91 uV/m
1610 kHz	35 uV/m

Minimum HAR Field Strength Recommendations

Based on the above considerations and on the data shown in Figures 4 and 5, the following minimum coverage area field strength contours can be derived:

a. 90% of vehicles at 530 kHz

Daylight operation, highway speeds -- 0.5 mV/m

24-hour operation, highway speeds --- 0.8 mV/m

b. 90% of vehicles at 1610 kHz

Daylight operation, highway speeds -- 3 mV/m

24-hour operation, highway speeds --- 8 mV/m

The results indicate abnormally high values of field strength required at 1610kHz to reach 90% of AM radio equipped vehicles. An explanation of these high values may be found in the two surveys referenced earlier. Survey I in

particular indicates that 55% of a 345 car sample would not tune to 1610kHz. It would therefore require very high signal levels to assure reception by 90% of a similar sample. If the designer accepts 80% as an acceptable percentage of vehicles capable of receiving a HAR message, the required field strengths are greatly reduced.

a. <u>80% of vehicles at 530kHz</u>

Daylight operation, highway speeds -- 0.4mv/m

24-hour operation, highway speeds --- 0.7mV/m

b. <u>80% of vehicles at 1610kHz</u>

Daylight operation, highway speeds — 0.7mv/m

24-hour operation, highway speeds --- 1.9mV/m

At these recommended levels, the effect of operating in an "urban" environment as opposed to a residential or rural environment should make only a minor difference. However, if there is a requirement for operating a HAR system in a particularly noisy industrial area (i.e. in which AM reception is known to be poor), or if there is some doubt as to what the noise environment actually is, it is recommended that noise measurements be made using a standard AM field strength meter. Audio monitoring will help assure that it is noise and not an AM carrier that is being observed.

Measurements should preferably not be made from, or very near an operating vehicle because of the contribution of the vehicle's own noise sources. The measured values will then consist of all external noise sources (including other vehicles making up the flow of traffic). A total RSS noise level can then be determined for design purposes by taking the square root of the sum of the squares of all determined from:

$$Em = \sqrt{(Et)^2 - (Ea)^2 - (Eg)^2}$$

where E_m = man-made noise

E_t = total noise level as measured

E_a = atmospheric noise as determined for the location, time of day and season that measurements were made

E_g = galactic noise, approximately = 0.6 uV/m

Atmospheric noise for all times and locations may be determined from the International Radio Consultative Committee (CCIR) Report No. 322, available from the International Telecommunications Union, Geneva, Switzerland. It is also available in many technical libraries in the USA. A simpler approach is to make measurements in daylight hours between November and April when atmospheric noise is known to be very low, and to ignore the atmospheric noise term altogether. Again, however, consideration must be given as to whether 24 hour HAR operation is desired and whether the source of the industrial noise is likely to vary substantially as between night and day.

It should not be overlooked that radio frequency noise is bandwidth related. A typical AM field strength meter, such as the Potomac Instruments FM-41 used to acquire the automotive noise data in Table 1 has an RF bandwidth of 7 kHz. This may also be taken as typical of automobile AM receivers.

Once a level of man-made, urban or industrial noise in determined, a total noise level for design purposes can be determined by taking the RSS value of all anticipated noise sources including the "own vehicle" noise and the highest anticipated mean levels of atmospheric nose. The latter will usually be that for a summer day or summer night, depending on whether daytime only, or 24 hour HAR operation is planned. Again, the best source for this information is CCIR Report 322. With the design value of RSS noise level, En, and relying on the data contained in Figures 4 and 5, a value for the minimum

field strength along the desired HAR coverage contour can be determined as follows:

a. <u>For X% of vehicles at 530 kHz</u>

$$E = E_x\ (E_n/27)\ \text{mV/m}$$

b. <u>For X% of vehicles at 1610 kHz</u>

$$E = E_x\ (E_n/9)\ \text{mV/m}$$

In the above equations,

E = minimum design field strength in mV/m

X = percentage of vehicles capable of receiving E in the presence of noise, En.

Ex = threshold value of field strength for given value of X, taken from Figure 4 or 5 as appropriate.

En = RSS noise level (see pages 16 through 18)

Recommended values of field strength may appear to be high, considering that a sensitive receiver with a tuning range extending to 530 and 1610 kHz will give a good response at much lower carrier levels. However, the data upon which the recommendations are derived are not based on the capabilities of a good receiver, but rather on a random sample of receivers actually installed without regard to age, condition, tuning range, or even the position of telescoping antennas. At the present time (1980), this is the population which HAR must reach.

CHAPTER 4

SYSTEM DESIGN OPTIONS

Basic Options

All HAR systems contain the following three components: a modulating source, a transmitter, and an antenna system. In the simplest configuration, the modulating source and transmitter are located in pole mounted weather-proof enclosures at a single site. The basic system layout is shown in Figure 6, below.

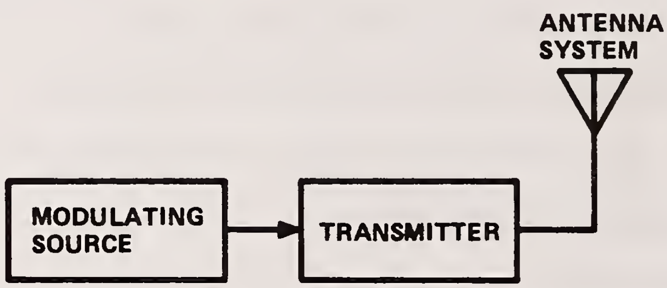


Figure 6. Basic HAR System.

Figure 7 shows an actual installation by the US Park Service of a design of this type. A disadvantage of this design is that the operator must visit the site periodically to change tapes and to turn the transmitter on or off. However, many systems, particularly those that do not require frequent message changes, operate in this manner.

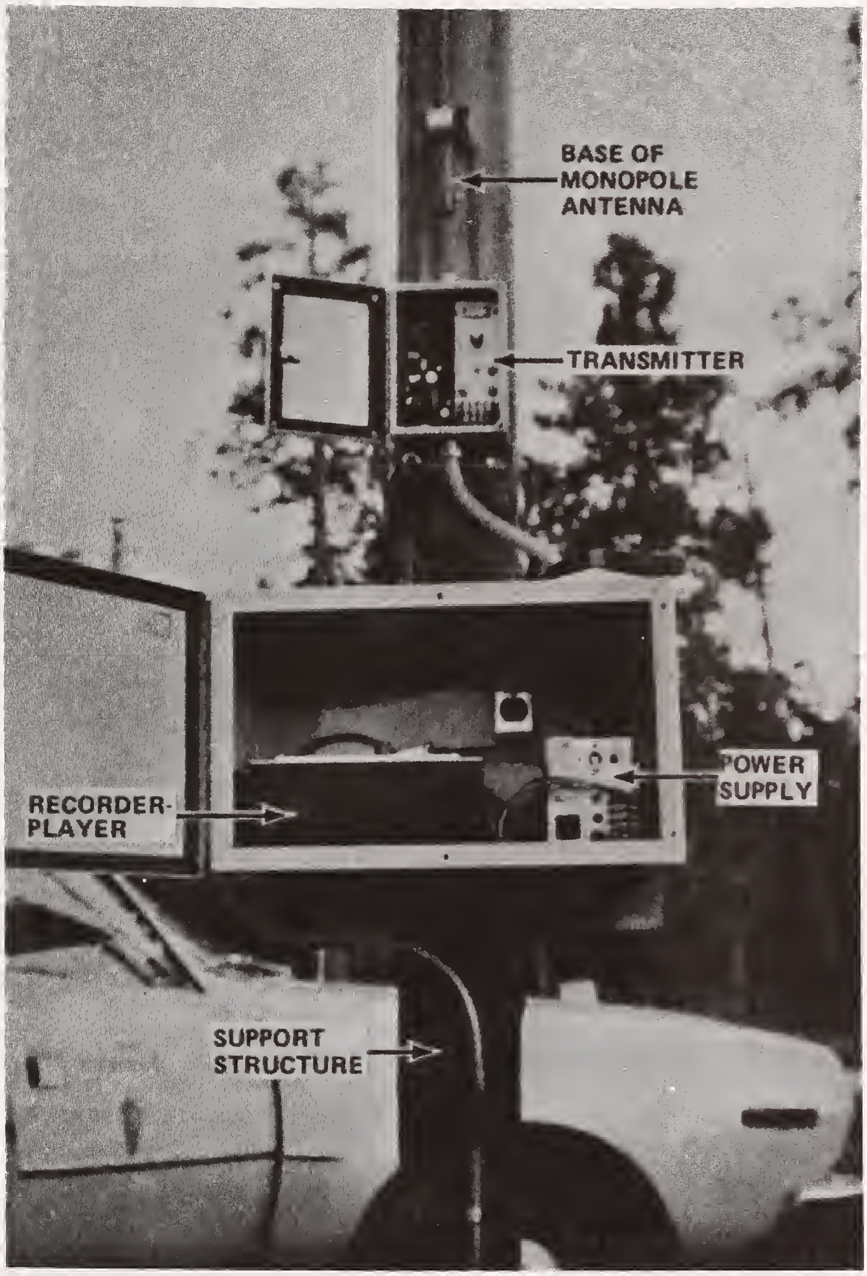


Figure 7. Basic HAR System Installed by U.S. Park Service.

In a more sophisticated configuration, control is exercised from a location remote from the transmitter. The "studio" or control point often times coincides with a traffic control center or other locations where information is collected. This type of design is illustrated in Figure 8. In addition to the three components of Figure 6, a leased telephone line interconnection between modulating source and transmitter is required. The use of a control console is a recommended operating convenience. A limiter amplifier is often beneficial. Although most HAR transmitters are designed for telephone line interconnection without the addition of a compressor-limiter amplifier, if line losses and fluctuations in line losses are excessive compressor-limiter amplifiers are recommended. The use of compressor-limiter amplifiers is further discussed in Chapter 9, "Telephone Line Interfacing." The system operated by Los Angeles Airport is an example of the design option shown in Figure 8.

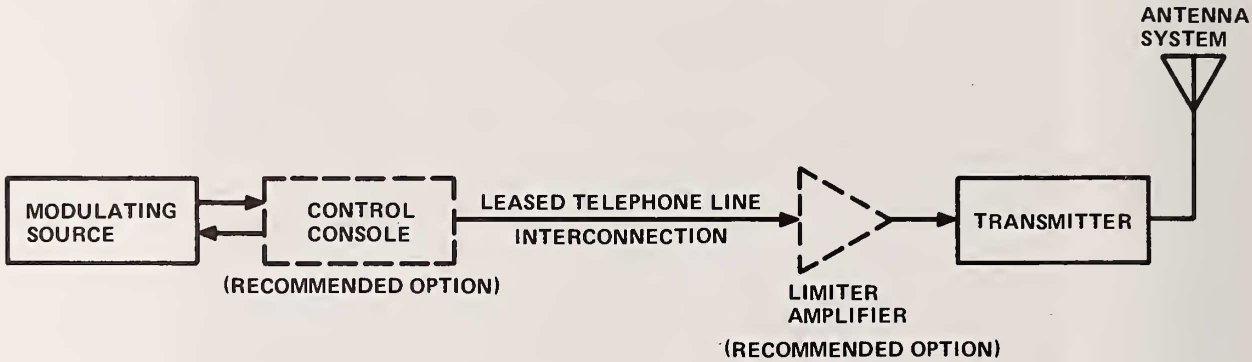


Figure 8. HAR System with Remote Modulating Source.

Another design option is illustrated in Figure 9.

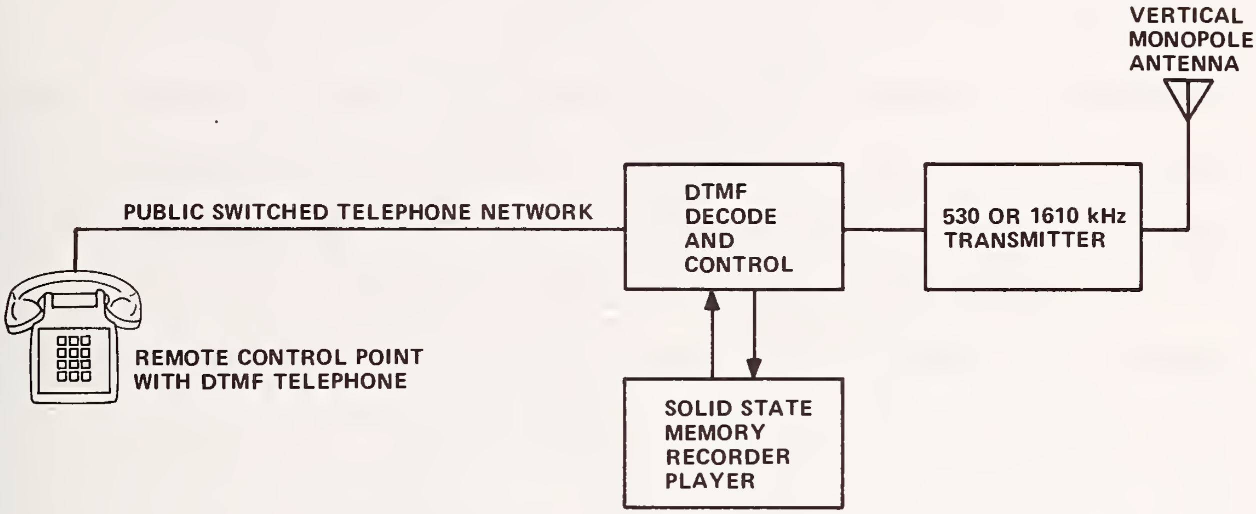


Figure 9. Control of HAR System via the Switched Telephone Network.

An installation of this type is currently operated by the Iowa Department of Transportation (See Appendix B). In this system, a solid state memory recorder-player is co-located with the transmitter. By dialing the appropriate number from a touch tone telephone and keying in the proper access and control codes, messages can either be monitored, recorded or played back. Dual tone multiple frequency (DTMF) control codes are used which allows control over the public telephone network from any standard touch tone instrument. However, control is restricted to persons having a knowledge of the control codes.

The system designer may also be required to provide wide area HAR coverage. This can be done with the ultastable transmitters as shown in figure 10. A system of this type is licensed to the City of Gatlinburg, TN. In this system, three stations are operated simultaneously on the same

frequency. This triples the area that could be covered with a single station. Since the same format is broadcast simultaneously, the same message is heard over the total area. An ultra-stable crystal oscillator in each transmitter is regional to assure that the carrier "beat" is below the audible range. Also, the delay characteristics of the telephone lines must be approximately equal to avoid the annoying echo effect that occurs when two identical audio messages, one delayed with respect to the other, are combined. This effect has been observed when the lines pass through separate telephone company central offices.

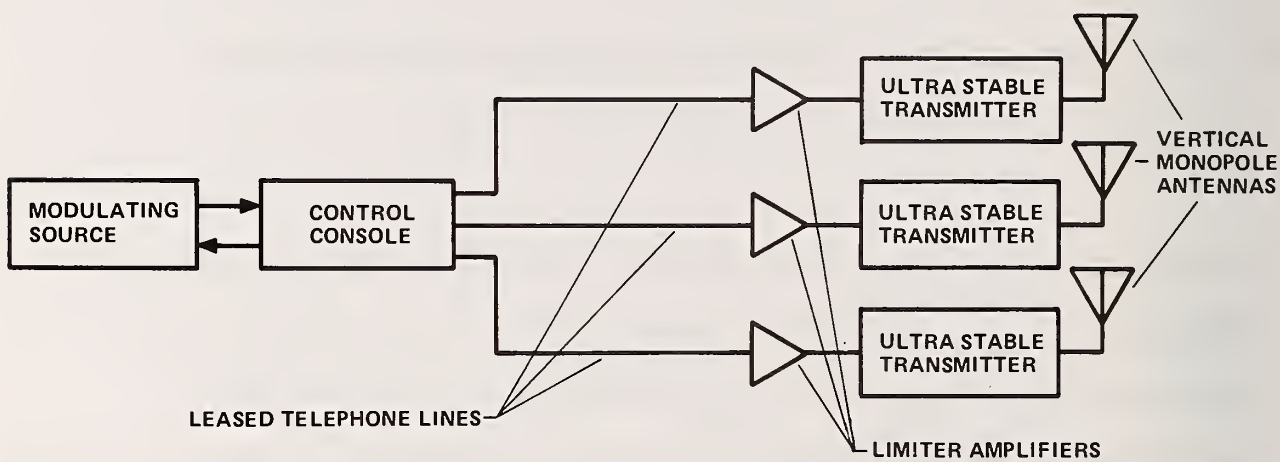


Figure 10. Multiple Station Wide Area Coverage System.

More elaborate designs are also possible. Figure 11 illustrates a HAR system proposed by the Ohio Department of Transportation for Cincinnati. In addition to the basic elements previously discussed this system has the following additional features:

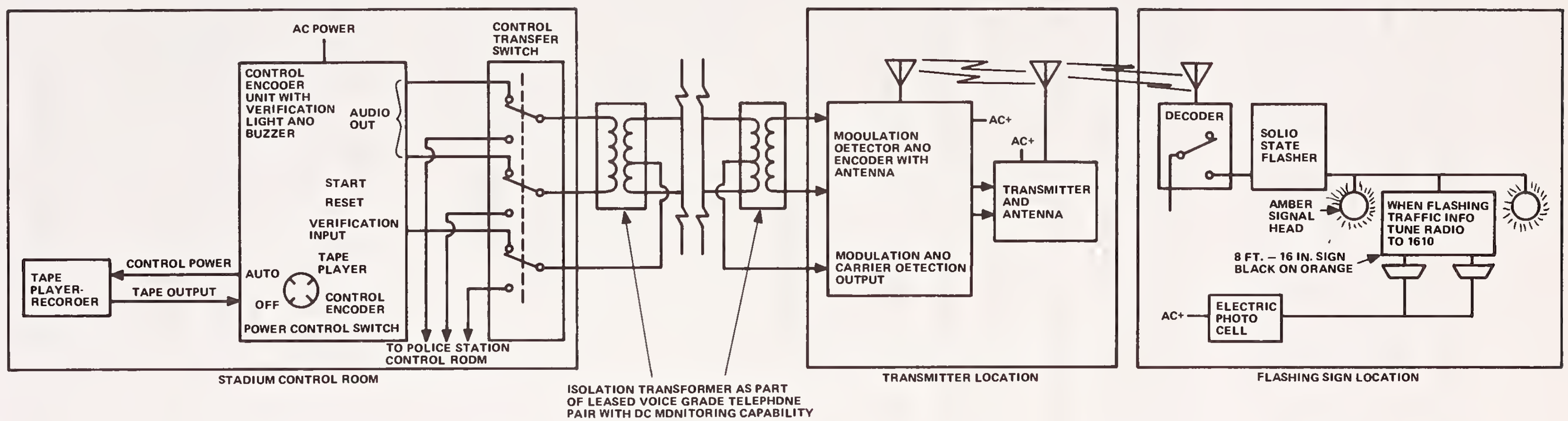


Figure 11. Proposed System Configuration for Cincinnati.

1. Alternate control point (i.e., the police station).
2. Ability to monitor the presence of carrier and modulation at the transmitter site.
3. Carrier actuated flashers on HAR alert sign.

Antenna Choices

As previously discussed, antenna choices are limited by the FCC Rules to conventional vertically polarized antennas and cable antennas. Conventional antennas include directional arrays. However, whether directional or omni-directional, a field strength limit of 2 mV/m at 1.5 km is applicable. In cable antenna systems the field strength is limited to 2 mV/m at 60 m and the overall cable length is limited to 3 km. A comparison of the 2 mV/m coverage contours is shown in Figure 12.

TIS COVERAGE LIMITATIONS

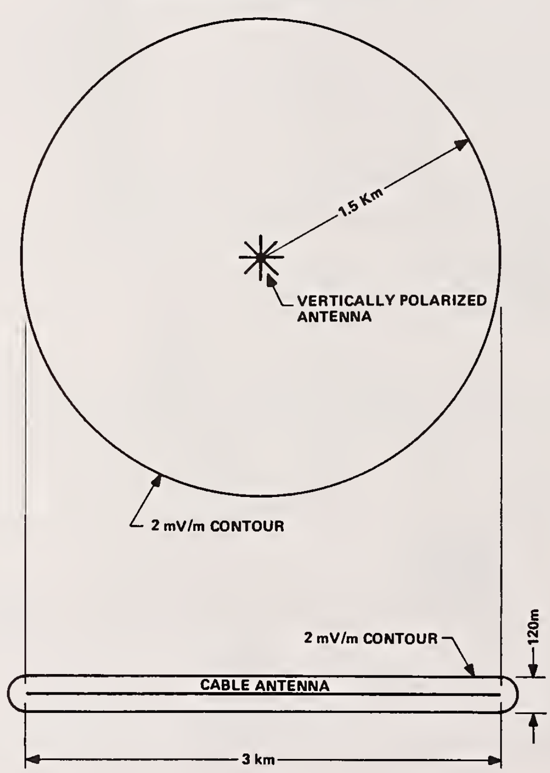


Figure 12. HAR Coverage Limitations.

It is apparent that a greater area can be covered with a "conventional" antenna than with a cable. However, conventional antennas also have a greater propensity for interference. The decrease in field strength with distance away from a typical cable antenna is quite rapid compared with that of a vertical monopole.

Directional arrays would have other than the circular pattern portrayed in Figure 12. The field strength in the direction of the main lobe is still limited to 2 mV/m at 1.5 km, so that the pattern, whatever its shape must still fit within the circular pattern shown in the figure. A directional array would be advantageous primarily in reducing radiation toward other stations susceptible to interference from HAR.

Some possible HAR design situations and the type of antenna favored are listed below:

Situation	Type of Antenna Favored
1. Coverage of a single stretch of highway--no HAR's in close proximity.	Monopole or cable
2. Simultaneous coverage of several roads in an area (e.g., several roads approaching an airport)	Monopole
3. Wide area coverage (e.g., park or recreational area)	Monopole
4. Two or more HAR's on same frequency and in close proximity (e.g., separate coverage of several roads in an area)	Cable
5. Operation in the vicinity of an AM broadcast station on second or third adjacent channel.	Cable or directional array

HAR System Components

A more detailed discussion of each of the major components of HAR stations (antennas, transmitters, voice recorders and telephone interfacing) is included in the chapters that follow.

CHAPTER 5

HAR TRANSMITTERS

The Transmitting System

A typical HAR transmitting system is shown in Figure 13. The general requirements of such a system is that it be efficient, reliable, easily installed and easily maintained. The system hardware must be capable of withstanding temperature and weather extremes. The system must be protected against vandalism and unauthorized tampering. The antenna radiation efficiency must be sufficiently high to result in an adequate field strength throughout the coverage zone with the limited transmitter power permitted by the FCC.

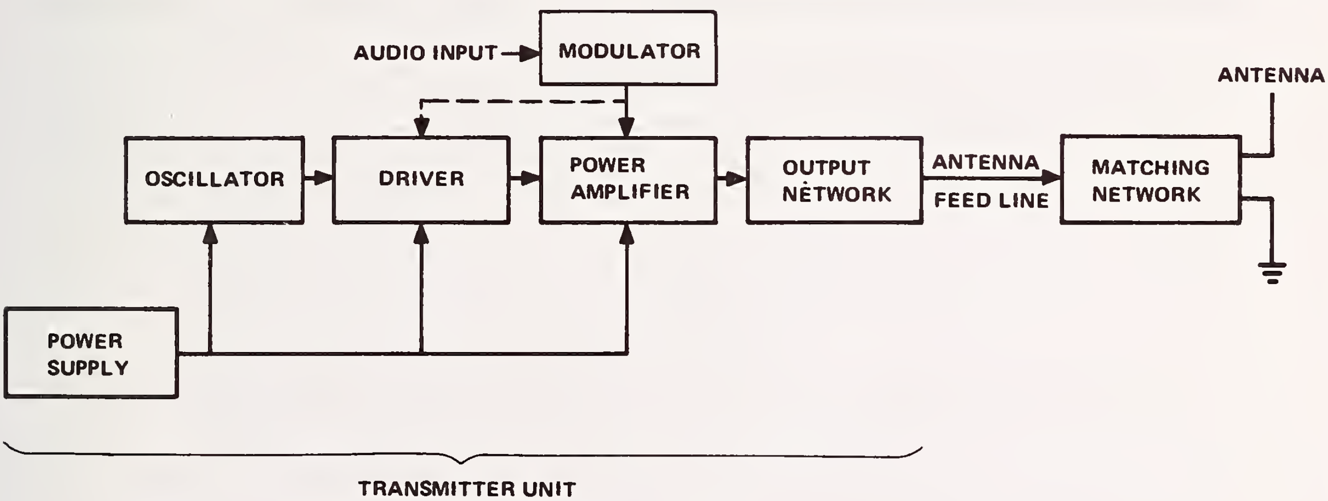


Figure 13. Typical HAR Transmitting System.

The power supply, oscillator, modulator, power amplifier, and output network are generally located within the transmitter unit of the low-power system and are usually referred to collectively as the transmitter. The oscillator frequency should be crystal controlled and set to either 530 kHz to 1610 kHz. The modulation is double side band AM. The power output may be adjustable from a fraction of a watt up to 10 watts for a vertical monopole antenna, or 50 watts for a cable antenna. Generally, the transmitter RF output signal connects to the antenna through a 50-ohm coaxial cable antenna feed line. Consequently, an output network in the transmitter is necessary to provide impedance matching between the final amplifier circuit and the 50-ohm output load. This network also serves as a narrowband filter to remove harmonics of the transmitter frequency.

Technical Standards

Listed below is a summary of the transmitter technical standards which a HAR transmitter must meet as extracted from Paragraph 2.988 and 90.242(b) of the FCC Rules and Regulations.

Type of Emission:	6A3 (amplitude modulation, voice, 6 kHz RF bandwidth) A0 (continuous carrier only) is permitted in leaky cable systems only for receiver quieting.
Frequency Tolerance:	100 Hz from -30 to 50 degrees C, and from 85 to 115 percent of the nominal value of the primary supply voltage.
RF Output Power:	Leaky cable systems -- 50 watts maximum, adjustable downward. Monopole antenna systems -- 10 watt maximum.

Modulation:	Unit must have overmodulation protection (typically a modulation limiter circuit). Modulation may not exceed 100% modulation with modulation input 16 dB higher than that required for 50% modulation.
Audio Frequency Response:	Unit shall be equipped with an audio low-pass filter which provides an attenuation between 3 kHz and 20 kHz which is greater than the attenuation at 1 kHz by at least 60 log (f/3) decibels. (equates to -50 dB at 20 KHZ.) Above 20 kHz the attenuation shall be 50 dB greater than the 1 kHz level.

Type Acceptance

The requirements for a type acceptance application are given in detail in Section 2.983 of the FCC Rules. In general, a complete technical description of the transmitter, including circuit diagram and photographs, must be submitted along with certified test results of the following tests:

DC input power
RF power output
Modulation characteristics (audio frequency response)
Modulation characteristics (modulation limiting)
Occupied bandwidth
Spurious emissions at antenna terminal
Frequency stability (temperature)
Frequency stability (input voltage variation)

Once accepted, a supplier may market duplicates of the unit as "type accepted", but he may make no alteration in the design as originally submitted to the FCC without changing the model designation and re-submitting new data.

All type accepted transmitting equipment in all radio services appears in the Commission's "Radio Equipment List, Equipment Acceptable for Licensing", issued annually.

Transmitter Specifications

The following HAR transmitter specifications set forth the minimum requirements for HAR stations:

Table 2 - HAR Transmitter Specifications - General

Table 3 - HAR Transmitter System Specification for Vertically Polarized Antennas

Table 4 - HAR Transmitter System Specification for Cable Antennas

It is recommended that these, or similar specifications be used by licensees in any purchase agreement or contract for HAR equipment and installation services. These specifications do not, of course, cover the particulars of the location, useage or special needs of the licensee. Such items also should be carefully detailed and included in the procurement documents.

Commercially Available Transmitters

A number of transmitters have now been given "type acceptance" by the FCC for use in HAR systems. Others, designed for low power applications such as drive in theaters and campus radio systems, are potentially useable for HAR with minor modifications. HAR transmitters may in general be classified into those which are limited to 10 watts or less maximum RF power output, and those exceeding 10 watts but with maximum limits of 50 watts or less. HAR systems employing conventional antennas may use only transmitters of the first category. Cable systems may use either. Any application for FCC authorization of a Travelers Information Station which proposes the use of a transmitter type accepted for greater than 10 watts with a conventional

Table 2. HAR Transmitter Specification - General. (Applicable to both cable and vertically polarized antenna systems)

Type Acceptance:	Transmitter must have met, or be capable of meeting FCC type acceptance for TIS.
Type of Emission:*	6A3 (double side band amplitude modulated voice)
Frequency:*	530 kHz or 1610 kHz
Frequency Stability (Temperature):*	+ or - 100 Hz, -30°C to 50°C
Frequency Stability (Voltage):*	+ or - 100 Hz from 85% to 115% of nominal value of primary supply
Occupied Bandwith and Spurious Emissions*:	At 100% modulation and rated RF power output, the amplitude of side band harmonics and other spurious emissions shall not exceed the following: (1) Down 25 dB, 5 to 10 kHz away from carrier (2) Down 35 dB, 10 to 25 kHz away from carrier (3) 43 dB below 1 watt at more than 25 kHz from carrier
Audio Input Impedence:	600 ohms nominal
Audio Sensitivity:	-15 dBm for 100% modulation with 1 kHz test tone. Adjustable over 30 dB range
Audio Response:	+1 dB, -3 dB from 0.3 kHz to 3 kHz, 1 kHz reference
Audio Rejection:*	A low pass filter is required between modulation limiter and modulated stage. The rejection characteristies of the filter and all other circuity between filter input and the input of the modulated stage shall be as follows: (1) 60 log (f/3) dB attenuation, 3 kHz to 20 kHz (1 kHz reference) (2) 50 dB attenuation, above 20 kHz (Note: f = frequency in kHz)

Table 2. HAR Transmitter Specification - General. (Applicable to both cable and vertically polarized antenna systems). (Cont'd)

Modulation Limiting:*	Modulation limiting characteristics shall be such that modulation will not exceed 100% when subjected to modulating signals 16 dB higher than those required for 50% modulation.
Audio Harmonic Distortion:	Less than 5%, 0.3 to 3 kHz at 67% modulation.
Audio Frequency Noise:	-50 dB at 67% modulation, 1 kHz reference.
Metering:	At least a capability of measuring modulation level and RF power (or antenna current) recommended.
Mechanical:	Transmitters intended for outdoor mounting shall be enclosed in a lockable, weatherproof metal box with means for mounting to post, pole or other suitable structure.
Primary Power:	117 VAC, 60 Hz, or as required.

*FCC requirement

Table 3. HAR Transmitter System Specification for Vertically Polarized Antenna.

Antenna Structure:*	Vertically polarized, not exceeding 15 m in height above ground.
Transmitter RF Output Impedance:	50 ohms resistive, or as required for match with antenna.
Antenna Input Impedance:	Antenna with matching network shall match transmitter impedence with a VSWR of less than 1.25 (i.e., nominally between 40 and 62 ohms resistive).
Transmitter RF Output Power:*	10 W maximum, adjustable downward. Adjustments to be made after installation if necessary to avoid exceeding 2 mV/m at any point at a distance of 1.5 Km from the antenna.
Preferred Transmitter Location:	The transmitter should be located at or below the base of the antenna so as to permit the antenna lead between transmitter and antenna to be oriented as near the vertical as practical.
Antenna Lead:	Copper wire not less than AWG #10 in size. If the transmitter must be displaced horizontally from the base of the antenna by more than a few feet, a horizontal run of 50-ohm coaxial cable will be required between transmitter and antenna structure. The coaxial cable must be grounded at the transmitter and at the base of the antenna structure.

* FCC requirement

Table 4. HAR Transmitter System Specification for Cable Antenna.

Antenna Structure:*	Radiating, (or induction) cable not exceeding 3 km in length, buried up to 0.6 m deep or secured to ceilings, bridge structures, tunnel walls, etc.
Preferred Feed Point:	Near center of cable through a matched "splitter" or power divider.
Transmitter RF Output Impedance:	50 ohms resistive.
Cable Input Impedance:	Cable with matching transformer (if required) shall match transmitter impedance with VSWR or less than 1.25 (i.e., nominally between 40 and 62 ohms resistive).
Transmitter RF Output Power:*	50 W maximum, adjustable downward. Adjustments to be made after installation if necessary to avoid exceeding 2 mV/m at any point distance 60 m or more from the nearest point of the cable antenna.
RF Transmission Line:	50 ohm coaxial (non-radiating) cable shall be used to connect the transmitter to the cable antenna.

*FCC requirement

antenna is likely to be rejected, even if the applicant proposes to operate the station at reduced power.

A list of commercially available transmitters of both categories are shown in Table 5 along with the manufacturer's specifications for each.

<u>Sample Testing of Four Transmitters</u>

Under FHWA auspices, four commercially available HAR transmitters were purchased and run through type acceptance tests by Atlantic Research Corporation. These units consisted of the following models:

1. Audio-Sine, Inc. Model AM-10WS (530kHz)
2. LPB, Inc. Model TX2-20, modified by addition of audio limiting circuit
3. Halstead Communications, Inc. Model TIS-20
4. Travelers Information Service, Inc. Model 34-366

The Halstead and Travelers Information Service, Inc. units were tested new. The Audio-Sine and LPB, Inc. units had been used in the field but were returned to the factory for check out and repair immediately prior to testing. Of the four, only the Halstead unit met all acceptance tests requirements on the first trial. The LPB, Audio-Sine and Travelers Information Service units passed acceptance test requirements after the following actions:

1. LPB Model TX2-20 - adjustments of audio levels in and out of the audio limiter circuit.

2. Audio-Sine Model AM-10WS - factory adjustment to audio filters and repair of a bad resistor connection in the emitter of the final amplifier.

3. TIS, Inc. Model 34-366 - Factory modification to the audio processor.

Table 5. Low-power AM transmitters FCC Type Accepted for HAR System.

Manufacturer and Model No.	RF Power Output (rms watts)	RF Output Impedance (ohms)	RF Harmonic Suppression	Frequency Stability[a]	Audio Frequency Response (1 kHz ref.)[b]	Audio Input Impedance (ohms)	Metering Capabilities	Comments
Audio-Sine, Inc. AM-10WS	2 to 10 adjustable	50, 100, 200 300, 500, 800	53 dB or better	20 Hz variation from -30 to 60°C	+13.5 to -10.5 dB from 0.3 to 3 kHz	8 to 16 nominal (600 is also available)	Power amp voltage and current, antenna current, audio level and modulation voltage, percent modulation	Several HAR sites and all National Park Service sites use this transmitter. This transmitter may require an inline amplifier to operate from a leased telephone line.
LPB, Inc. TX 2-30 TIS	2 to 30 adjustable	50	60 dB or better	97 Hz variation from -30 to 50°C	+0 to -5.7 dB from 0.3 to 3 kHz	600 balanced	Percent modulation relative power output	This unit replaced the LPB25C.
Halstead Communications, Inc. Mod. TIS-20	4 to 10 adjustable	50/70 unbalanced	40 dB or better	+10 Hz variation from -20 to 50°C	+0 to -6 dB from 0.3 to 3 kHz	5,000 unbalanced	Indicator lamp for RF matching flashing lamp for 95 percent modulation	This unit is part of the HALSTEAD HAR system. It has obtained type acceptance in Canada.
Travelers Information Service, Inc.[d] Model No. 34-366.	Up to 10 adjustable	50	64 dB or better	82 Hz variation from -40 to 90°C	+0 to -6.4 dB from 0.3 to 3 kHz	5,000 unbalanced	None at this time. Planning an entire test set for transmitter and antenna.	This unit is designed around a monopole TIS system.
Travelers Information Service, Inc. Model No. 34-376	Up to 50 adjustable	50	64 dB or better	Not measured[c]	Not measured[c]	5,000 unbalanced	None at this time. Planning an entire test set for transmitter and antenna.	This unit designed for cable systems. It is the only 50W unit currently available.

[a]Measured on a purchased sample.

[b]Measured on a purchased sample. Variation of input for constant percent modulation. "+" means more gain, "-" means less gain.

[c]Expected to be approximately the same as Mod No. 34-366.

[d]Also sold by Radio Systems, Inc. as Model No. TR-20-TIS. The design is identical.

Ultra Stable Transmitters

As HAR has evolved, there has developed a need to operate multiple stations on the same frequency simultaneously broadcasting the same message (Refer back to Chapter 4, Figure 10). Although transmitters now available meet FCC standards with respect to frequency stability, the standards are not strict enough to avoid annoying "beats" or "heterodynes" caused by small differences in the frequencies of transmitters operating in the same general area. The beat between two transmitters can be heard in an automobile receiver output even if the radio signal from the more distant transmitter is very much weaker than the near transmitter. To solve this problem, two commercially available transmitters have been modified by Atlantic Research Corporation by adding an ultra stable oscillator to each, reducing the deviation from the assigned frequency to less than $\pm$ 1 Hz. The maximum possible beat is therefore 2 Hz, well below the range of audibility. Both have been type accepted and used in licensed HAR operations. Shown below are the composition and type acceptance designation of each:

Basic Unit	Oscillator	FCC Designation	Type Acceptance Status
Audio Sine AM-10WS	Vectron CO-214	JB-1C	Accepted 6/79
Halstead TIS-20	Vectron CO-214	TIS-20/SOM	Pending

Another technique for operating multiple stations in close proximity on the same frequency is synchronization of all transmitters to the same source. This has not yet been demonstrated with HAR (1980). However, systems of synchronized low power transmitters have been successfully employed by Radio Systems, Inc. in campus radio systems. This has been done with Model No. TR-20-TIS transmitters equipped with phase lock loops. A synchronizing tone above the audio is transmitted over telephone lines to each transmitter from

the program source. The oscillator frequency of each transmitter is divided down and compared with the synchronizing tone in the phase lock loop. Any difference between the two produces an error signal which acts to correct the oscillator frequency. There appears to be no reason why this technique would not work equally well for HAR.

CHAPTER 6

MONOPOLE ANTENNA CHARACTERISTICS

The antenna most commonly used for HAR systems is the electrically short, vertical monopole. It consists of a tuned vertical conductor driven against a ground plane. It is "electrically short" because FCC restrictions on height limit it to something much less than a resonant quarter wavelength. It radiates a vertically polarized omnidirectional signal. The coverage obtainable for a given RF power input is related to the efficiency of the antenna system (including the ground plane and antenna matching network) and the characteristics of the surrounding terrain. The coverage theoretically obtainable for both "good" and "poor" soil conductivity of surrounding terrain is illustrated in Figures 14 and 15 respectively for 530kHz and 1610kHz. Both figures assume that the designer achieves the maximum allowable field strength of 2 mV/m at 1.5 km. With 10 watts input power this requires an overall efficiency of 1% to 3% at 530kHz, and 1% to 17% at 1610kHz. In fact, this is much more difficult to achieve than may first appear.

Factors Affecting Efficiency

In general, an electrically short vertical monopole over ground suffers on two counts: inherently, it is an inefficient radiator, and its base impedance consists predominantly of a high value of capacitive reactance. The antenna matching network cancels the capacitive reactance and transforms the remaining antenna resistance to 50 ohms to match the transmitter output

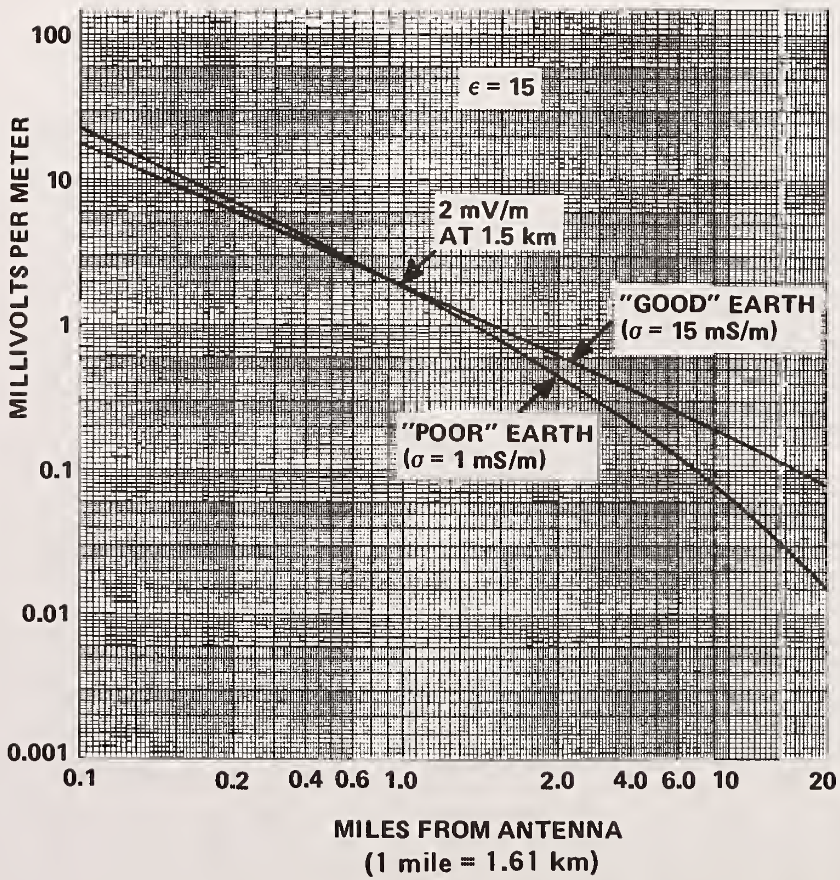


Figure 14. Maximum HAR Coverage at 530 kHz for "Good" and "Poor" Earths.

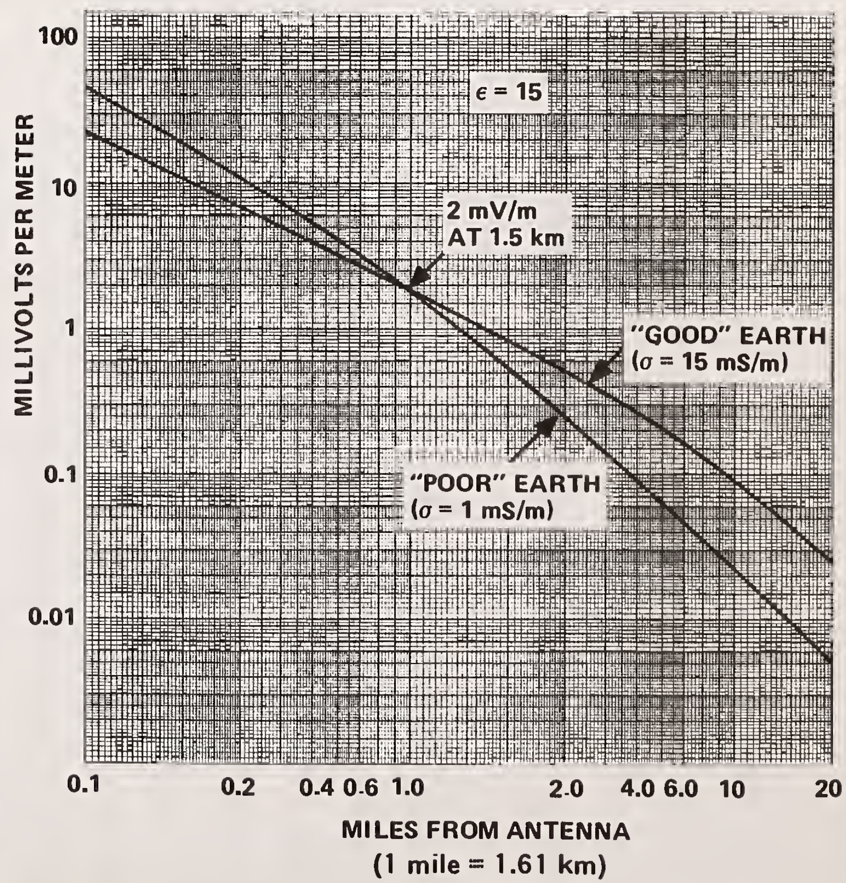


Figure 15. Maximum HAR Coverage at 1610 kHz for "Good" and "Poor" Earths.

impedance. The matching network cannot improve the basic antenna efficiency and, in practice, must always degrade the antenna efficiency further because of unavoidable ohmic losses in the matching coil.

Antenna Impedance

Electrically, the short monopole can be represented by a resistance in series with a small capacitor as shown in Figure 16.

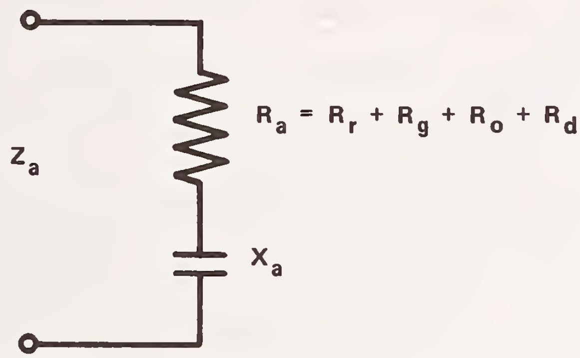


Figure 16. Equivalent Circuit of a Short Monopole.

The antenna resistance Ra is effectively the sum of the following resistances:

Rr = Radiation resistance. Power dissipated in this resistance is equivalent to the power radiated from the antenna. The value of Rr for a short monopole is very small, e.g. 0.02 ohm for a 4.6 m monopole at 530kHz.

Rg = Ground resistance. Power dissipated in this resistance is equivalent to power absorbed by the ground due to near field currents induced into the earth near the base of the antenna. This may be on the order of 20 ohms in typical HAR installations.

Rx = Ohmic resistance. Power dissipated in this resistance is equivalent to antenna power lost in ohmic heating of the conductors in the antenna structure. This resistance may be neglected for small monopoles.

Rd = Dielectric resistance. Power dissipated in this resistance is equivalent to the antenna power lost in the dielectric insulator that isolates the antenna element from ground. Although for some types of

short monopoles this resistance can be appreciable, especially when the insulator is wet, the dielectric resistance in this discussion is neglected or may be considered to be included with the ground resistance.

Curves of the radiation resistance and reactance for a monopole over a perfect ground plane are presented in Figure 17. It can be seen that the radiation resistance increases approximately as the square of antenna (electrical) height and, therefore, becomes small rapidly as the antenna becomes electrically short. The antenna reactance depends on the "fatness" of the antenna element, where "fatter" antennas tend to be less reactive.

Ideally, the antenna should be close to one-quarter wavelength in height at which point the radiation resistance is large and the reactance nearly vanishes. A monopole of this size does not require matching and is an inherently efficient radiator. On the other hand, all HAR monopoles are restricted by FCC height limitations to height/wavelength ratios of less than 0.08.

The curves in Figure 17 do not account for ground resistance Rg. In a practical case, a monopole installed over real earth has a total resistance larger than the radiation resistance due to the addition of ground resistance. As a result, the antenna is inherently inefficient as shown by the following expression for antenna radiation efficiency.

$$\text{eff.} = \frac{\text{Power radiated}}{\text{Total power delivered to antenna}} = \frac{I^2 Rr}{I^2 Ra} = \frac{Rr}{Ra} = \frac{Rr}{Rr + Rg} \cong \frac{Rr}{Rg}$$

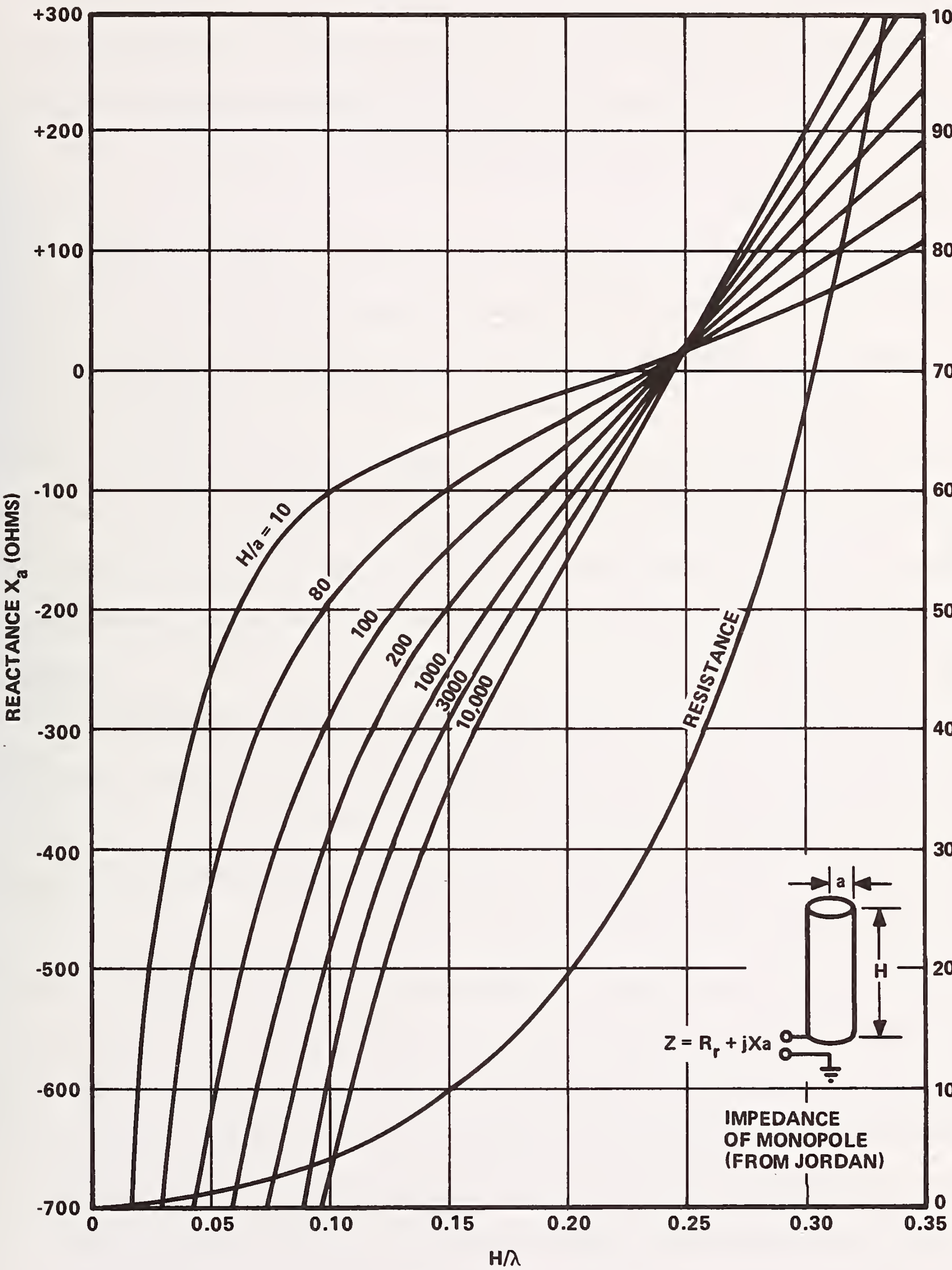


Figure 17. Impedance of Monopole Antenna over Perfect Ground.

Antenna Matching

Maximum power transfer from transmitter to antenna requires that the impedance of the two be "matched". Since most transmitters are designed to match a 50 ohm load, the input impedance of antenna systems should also approximate 50 ohms.

A common method of providing a match between a transmitter and an unmatched antenna system is to utilize a "matching network". Although more complex designs are often used, a matching network requires a minimum of two elements arranged in either a shunt-series or series-shunt combination. Such a network can be designed to match any impedance to a given transmitter impedance at a given frequency. However, if the network requires large inductive elements, it can introduce substantial losses. This is normally the case when a matching network is used at the base of an electrically short monopole, which characteristically has a very high capacitive reactance. The matching network requires either a large series or shunt inductor to compensate for this reactance. The inherent resistance of the inductor becomes a part of the load to which the transmitter must be matched, thus affecting the design of the matching network. A method of determining matching network design values for short monopoles is covered in a later section.

The inductive reactance required to match a short monopole need not be located at the base. Matching inductors (often referred to as "loading coils") are often built into the antenna itself. The size of the inductor becomes larger as its distance above the base increases. However, the efficiency of the antenna is actually increased up to a point, above which it begins to decrease. Studies have shown that the greatest efficiency is achieved with a matching inductor located between one-half and two-thirds the distance from base to tip of the monopole.

The effect of a lossy inductor on antenna system efficiency can be determined from the quality factor or "Q" of the inductor. The efficiency of a matching inductance is approximately:

$$(Eff.)_m = Q_m/(Q_a + Q_m)$$

where

$Q_a = X_a/R_a$

X_a = capacitive antenna reactance

R_a = total antenna resistance, including ground resistance

$Q_m = X_m/R_m$

X_m = inductive reactance

R_m = resistance of the inductor

If Q_m is equal to or less than Q_a, not an unlikely situation in a HAR antenna system, 50% or more of the transmitter power will be dissipated in the inductor.

One other means of improving the performance of an electrically short monopole is by means of capacitive top loading. This is accomplished by adding to the top of the monopole a disk, an array of radial extensions, or an "umbrella" formed from supporting guy wires. The effect of any of these is to add capacitance (i.e. decreasing the capacitive reactance). The antenna behaves as though its height were increased. The size of the inductive reactance required for matching is reduced. As a consequence, the antenna and its matching network becomes more efficient. This technique has not been used in existing HAR systems. However, it has been demonstrated with short antennas at HAR frequencies, as discussed in a later section of this chapter.

The designer of an antenna matching network must consider the voltages that develop across the elements. Since an electrically short antenna is

highly reactive, the corresponding matching network is also highly reactive, and due to the fact that the final tuning establishes a resonance condition, the voltages across all reactive elements including the voltage on the antenna element itself are generally quite high, even at low power levels.

Antenna Bandwidth

From the preceding discussion, it may be concluded that the higher the Q of a matching inductor, the better the design from the standpoint of efficiency. However, the Q of this inductor may also affect the antenna bandwidth. The minimum tolerable bandwidth in a HAR system in order to pass a double sideband AM signal modulated with frequencies up to 3kHz, is 6kHz. The bandwidth of a short monopole antenna is a function of the antenna reactance and resistance (including ground resistance), loss resistance of the matching inductance, and the source resistance of the transmitter (which in a matched condition equals the input resistance of the antenna system with matching network). It is approximated by:

$$\text{bandwidth} = 2f\ (Qm + Qa)/QmQa$$

where f = frequency (i.e., 530 kHz or 1610 kHz) and Qm and Qa are as previously defined.

It should be noted that, if the two values of Q differ by much, it is the lower value of Q that governs. In the case of an antenna with very low losses (e.g. an antenna with a good ground system) Qa will be very high. In such a case the Q of the matching coil (Qm) at 530 kHz could not exceed about 180 without unacceptably restricting the bandwidth.

In a practical design the bandwidth should be at least 50 to 100% greater than the minimum required to allow for possible drift in the values of antenna and matching network reactances. Extremes of temperature and humidity can

cause small changes in reactance and thereby causing shifts in the frequency to which the system is tuned. However, since lower values of Q result in lower efficiency as well as greater bandwidth, there is inevitably a trade-off between bandwidth and efficiency.

The efficiency of a short monopole antenna of a given bandwidth over an ideal ground plane, and thus the maximum efficiency obtainable with any short monopole, is approximated by:

$$\text{maximum efficiency} = \frac{3.06h^3fo^4}{\Delta f[\ln(2h/a)-1]}$$

where

- h = antenna height in m
- fo = design frequency in MHz
- Δf = bandwidth in Hz
- a = antenna radius in m

This approximation assumes that antenna heights do not exceed about 0.1 wavelength, and that bandwidths are limited by matching inductor losses and not by radiation resistance (i.e. $Rm \gg Rr$). These conditions are all met over the range of values permitted in HAR applications. As an illustration, consider the following conditions:

- antenna height: 10 m
- antenna diameter: .038 m
- desired bandwidth: 9 kHz (9,000 Hz)
- design frequency: 530 kHz (0.53 MHz)

The maximum efficiency is computed as 0.51%. Under practical conditions, the actual efficiency will always be less than this. The maximum efficiency will increase to 1.6% if antenna height is increased to FCC limit of 15 m. It can also be increased by the use of capacitive top loading or helically wound

antennas, both of which are described in a later section on the custom design of vertical monopoles.

Propagation Characteristics of Vertical Monopoles

For a short vertical monopole over a perfectly conducting earth, the field strength at 1.5 km would be:

$$Einv = \sqrt{40\ Pr}$$

where Einv is the "inverse distance" or "unattenuated" rms field in mV/m, and Pr is the radiated power in watts. Einv is the ideal field strength that would exist if there were no losses induced by the earth. Its value changes inversely with distance from the antenna. Thus, the field strength at 3 km and 6 km would be respectively one-half and one-quarter of the value of Einv given above. The radiated power, Pr, is the transmitter output power multiplied by the efficiency (expressed as a fraction) of the antenna system including matching network. If antenna and matching network efficiencies are separately determined, the overall efficiency would be the product of the two.

The actual field strength at 1.5 km will be less than Einv because of earth effects on the dominant ground wave mode of propagation. The two critical earth parameters are the dielectric constant, usually symbolized by the Greek letter "ε", and the conductivity, symbolized by the Greek letter "σ". Of the two, the conductivity is the most prominent at HAR frequencies, the effect of dielectric constant being very small at high values of conductivity. Until recently, it was common to express earth conductivity in millimhos per meter (mmhos/m) and these units will be found in much of the literature dealing with ground wave propagation. Under current SI standards, the appropriate unit is "millisiemens per meter" (mS/m). Typical values of dielectric constant and conductivity are:

	ε	σ(mS/m)
Dry, sandy flat coastal land	10	2
Marshy, forested flat land	12	8
Rich agricultural land, low hills	15	10
Pastoral land, medium hills and forestation	13	5
Rocky land, steep hills	10	2
Mountainous land	5	1
Residential areas of cities	5	2
Industrial areas of cities	3	0.5 or less

Curves prepared by the FCC for determining the effect of earth conductivity or propagation are published in Section 73.184 of the FCC Rules. Two sets of these curves, appropriate for use with the 530kHz and 1610kHz HAR frequencies, are shown in Appendix B. These are standardized to a dielectric constant of 15. Some error can be expected at low values of conductivity (2 mS/m and below) if the actual dielectric constant deviates appreciably from 15.

Also given in Appendix C is an earth conductivity map of the US which may be used with the propagation curves. The map is of necessity based on broad averages. Local conditions may vary considerably. One method of determining the effective conductivity for a given transmitter site is a technique known as "curve matching". The requirements for curve matching in connection with AM broadcast station applications (not required for HAR station applications) are given in Section 73.186 of the FCC Rules. Specifically, measurements of field strength are made along a radial from the antenna site. The resulting measurements are plotted on a graph of identically the same size and dimensions as the propagation curves in Appendix B. Then with the aid of a light table or other brightly lighted surface (e.g., a window) the graph of measured data is placed over the published curves and moved up and down until a "best match" of the measured data with one or more of the family of propagation curves is found. This process is illustrated for two commercial HAR antennas sited in

Gainesville, Virginia in Figures 18 and 19. In the figures it may be noted that the conductivity appears to change from 1 mS/m to 2 mS/m beyond a certain distance. This break is typical in such measurements, as is the scattering of the measured points. The expected earth conductivity from the FCC conductivity map (see Appendix C) for the Gainesville area is 2 mS/m.

There are methods of measuring surface conductivity directly, such as laboratory measurements of soil samples. However, these may give very misleading results and should not be depended upon for purposes of propagation predictions. Surface waves at 530 and 1610kHz penetrate deeply into the earth and are affected by sub-soil as well as surface conditions. This penetration is less at 1610kHz than at 530kHz, hence the differences in conductivity observed in Figures 18 and 19. Also, the effective conductivity over an area may be an averaging of highly variant local conditions. For example, tests made of moist surface soil samples taken from the Gainesville site previously referred to showed an average of 16 mS/m. Clearly this does not agree with the effective conductivity for the area as determined from either the FCC conductivity map (Appendix B) or the measurements shown in Figures 18 and 19.

Of particular interest to HAR system designers, because of FCC restrictions, is the actual field strength at 1.5 km. This is given in terms of the inverse distance field in the following table:

Conductivity (mS/m)	Ratio, Actual to Inverse Distance Field Strength	
	530kHz	1610kHz
0.5	0.59	0.24
1.0	0.74	0.32
2.0	0.88	0.46
4.0	0.94	0.66
6.0	0.97	0.78
8.0	Approx. Equal	0.83
10.0	Approx. Equal	0.87
20.0	Approx. Equal	0.93
30.0	Approx. Equal	0.97

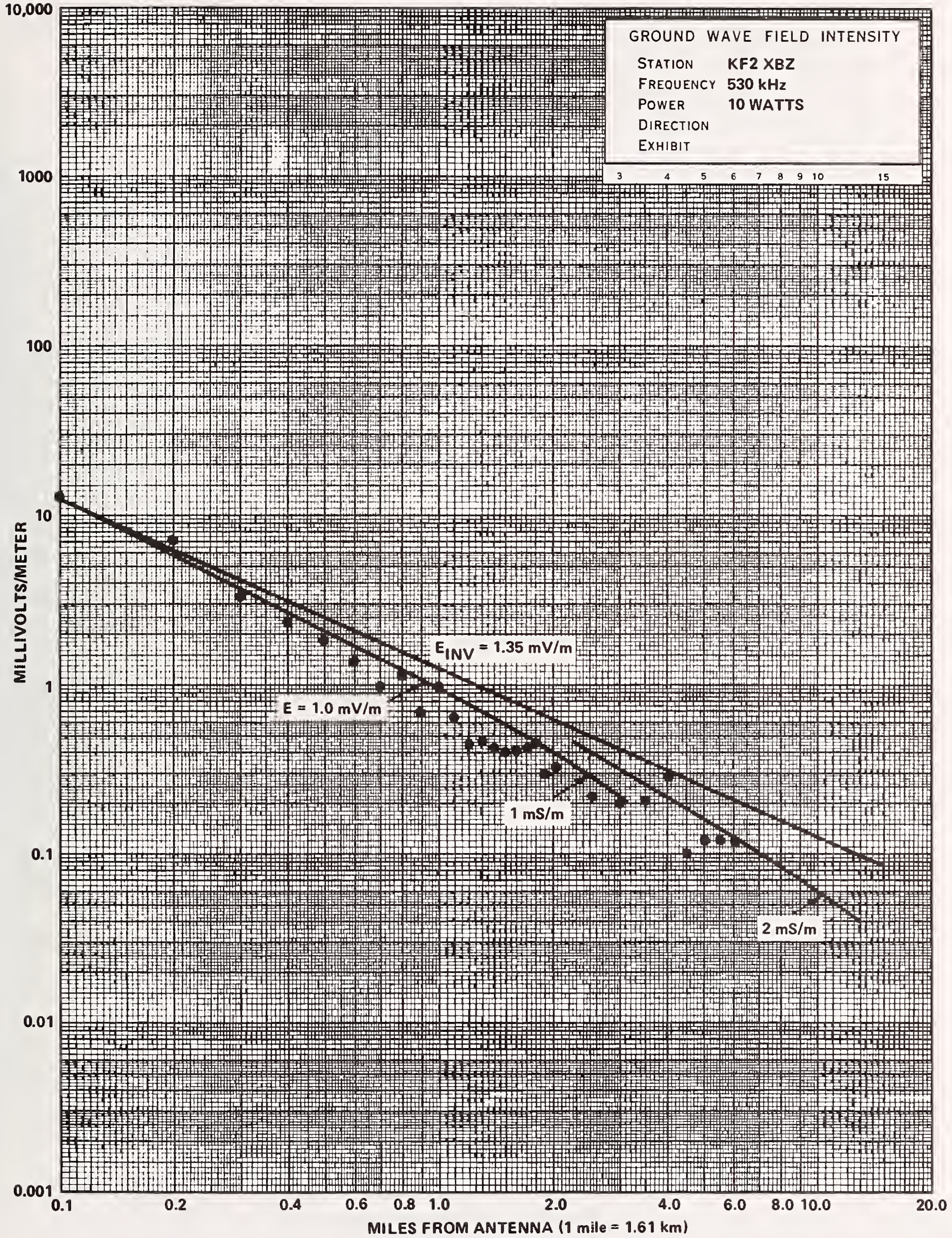


Figure 18. Field Strength Measurements, Morad SF530 Antenna.

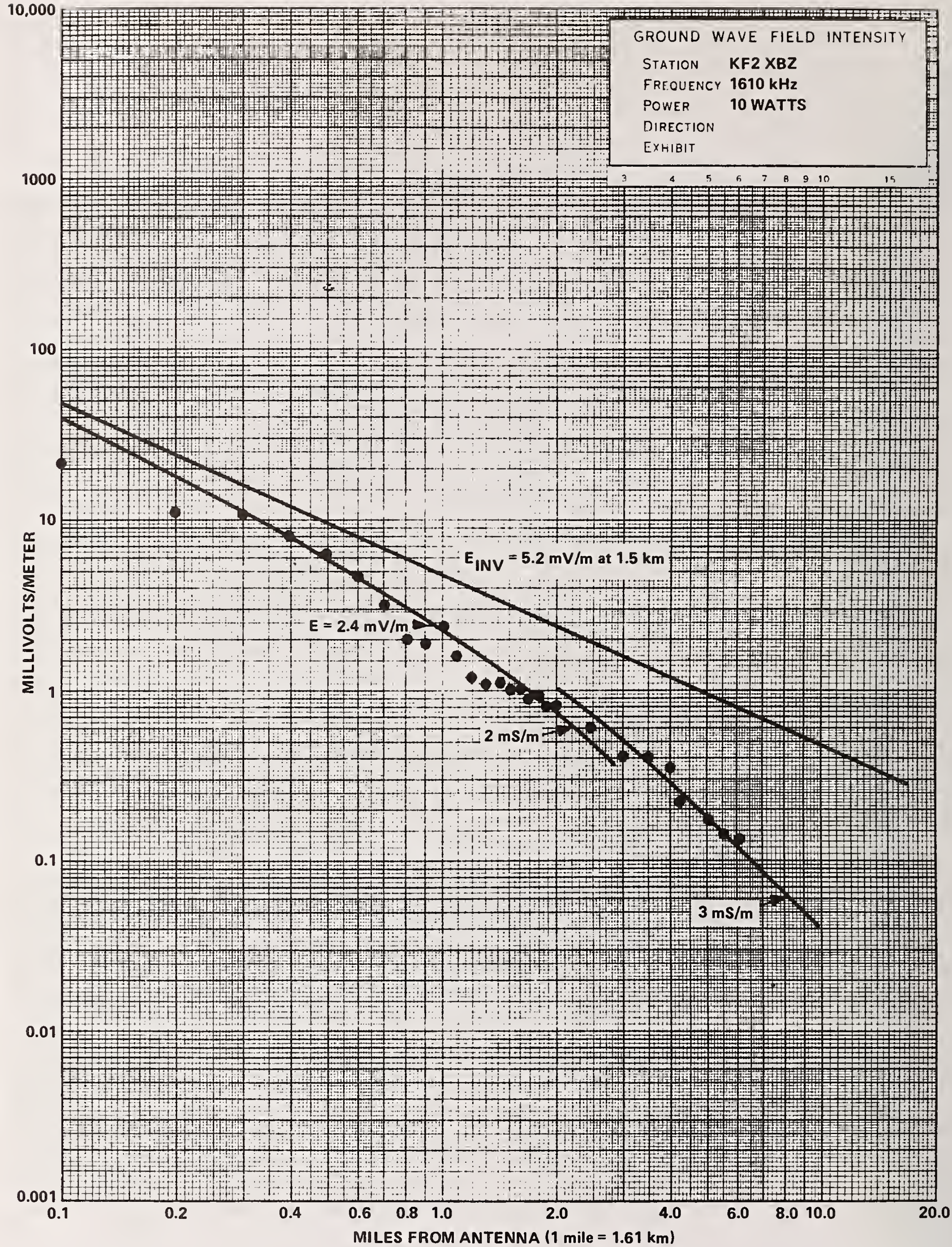


Figure 19. Field Strength Measurements, Morad SF1610 Antenna.

Ground Plane Design

Ground resistance is the one most critical factor affecting the efficiency of a short monopole. A good ground system is therefore essential for efficient radiation regardless of the specifics of the monopole design itself. A variety of grounding systems have been successfully used in HAR systems. There are examples of the use of a building's existing grounding sources, as at Minneapolis International Airport. The most common grounding sources in a building include its structural steel and its copper water pipe system. Another method of establishing an RF ground is by driving one or more ground rods into the earth near the base of the antenna. These are typically the standard 2.4 m copper or copper clad ground rods often used for establishing power or lightning grounds. Their effectiveness depends on the soil conditions with moist, rich earth giving better results than dry sandy or rocky soil. The Virginia Department of Highways found this type of ground adequate for their HAR system in the Richmond area, although the system did not achieve the range that would have been permitted under the FCC Rules.

The most efficient ground plane is likely to be a system of radial ground wires arranged in a circle like spokes of a wheel. In commercial broadcast practice, these may number 120 and may be one-quarter wavelength long. Space and budgetary limitations may require simpler designs for HAR antennas. If the system makes use of commercial AC power, as nearly all do, the power ground will unavoidably become part of the antenna ground system. This may account for the fact that some antenna installations have been found to radiate tolerably well with what would otherwise appear to be a rather inefficient grounding.

Figure 20 shows measurements made of the impedance of a 9.1 m monopole. Ground radials used with the monopole were varied in length from one-half to twice the antenna height, and in number from eight to two. However, also part of the ground system was the power ground, consisting of the third (ground) wire in a 76 m extension cord used to power the signal generator employed in the measurements. This situation is, in fact, normal for any HAR system connected to the commercial power grid. The ends of the radials were pinned to the earth with 200 mm spikes. The surface layer of earth at the antenna site was damp at the time of the measurements and was determined in laboratory tests to have a conductivity of about 16 mS/m.

The curves shown in Figure 20 are linear least-squares fit to the available data. It may be observed that the resistance (which is primarily ground resistance) does not change appreciably with radial length, but changes significantly when the number of radials is changed. In fact, a single 1.8 m ground rod at the base of the monopole gave lower resistance than did the use of only two ground radials. It is probable that the multiple grounding points resulting from pinning the ends of the radials to damp earth had greater effect than the lengths of the radials.

Antenna capacitance may be seen from Figure 20 to increase with either length or number of radials. The capacitance varied about 4% between radial lengths of 0.5 to 3 times monopole height, and 3% as between 2 and 8 radials. A single 1.8 m ground rod gave a slightly higher capacitance reading than a system of two radials, and about the same as a system of eight radials out to a length equal to twice the monopole height. However, this may be partly due to the good ground conditions known to exist. It is likely that a ground rod in poorly conducting earth would be less effective than a system of radials.

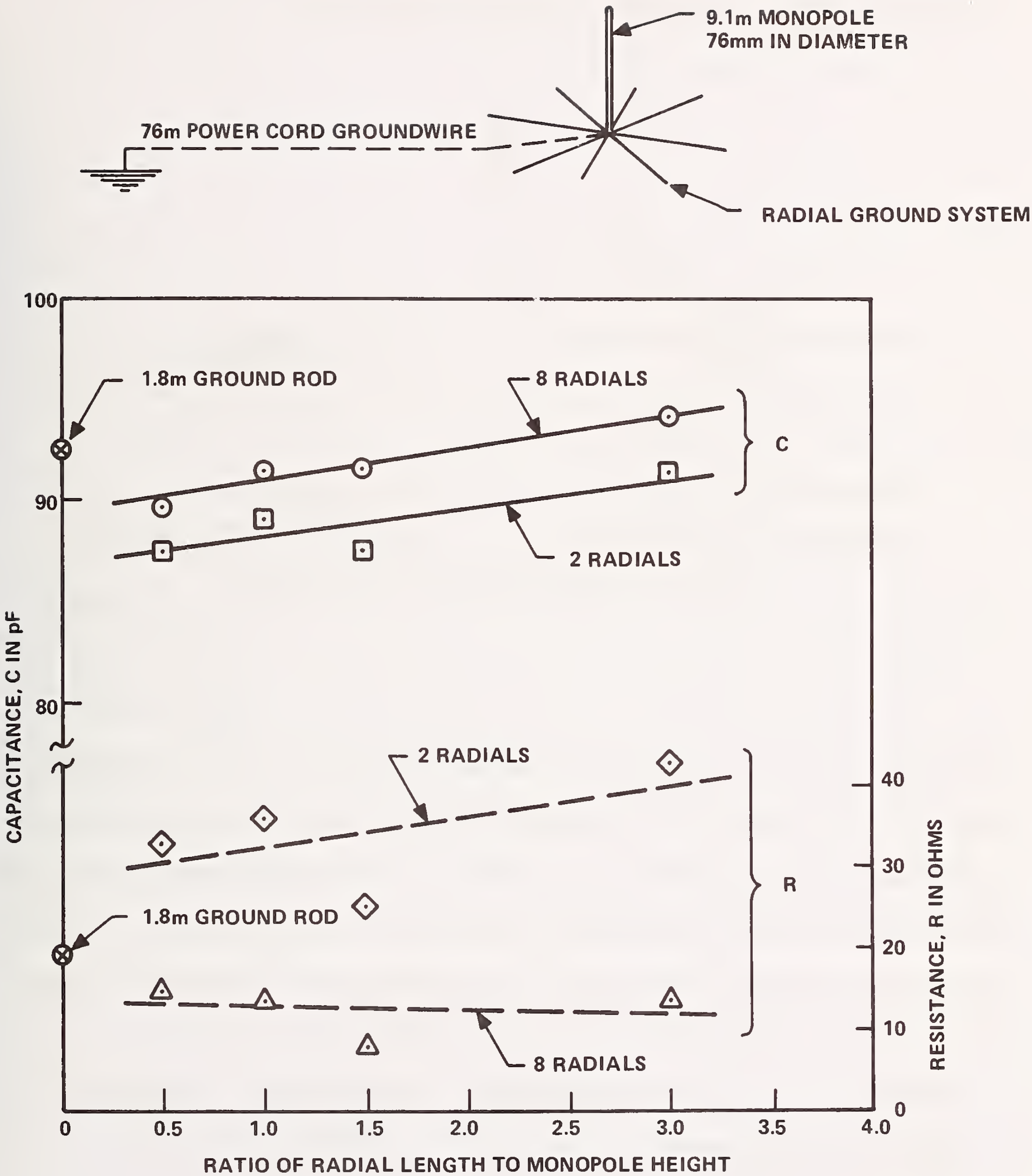


Figure 20. Antenna Capacitance and Resistance Measurements for Varying Length and Numbers of Ground Radials at 1610 kHz.

Figure 21 shows two ground radial configurations used in tests to determine the importance of symmetry in ground plane design.

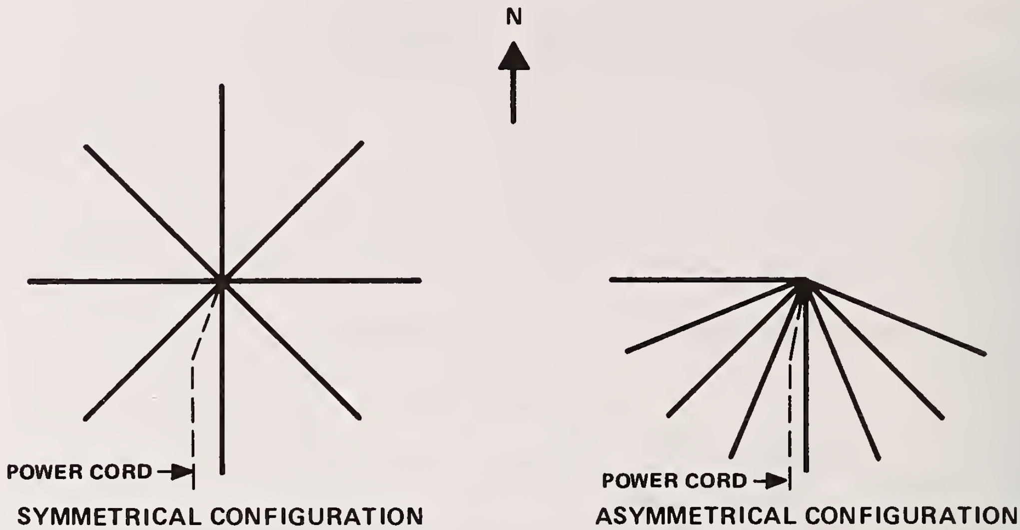


Figure 21. Comparison of Ground Radial Systems.

Radials were 13.7 m in length. Measurements were made using commercial monopoles at 530 kHz and 1610 kHz, respectively using both the symmetrical and asymmetrical patterns shown in the figure. Field strength measurements were made at 1.61 Km along a semi-circle beginning at 18 degrees east of north and continuing clockwise to 182 degrees. The following is a comparison of the root-mean-square (RMS) values of the measurements made:

530 kHz	Symmetrical	Asymmetrical	Change
RMS, all measurements	.77 mV/m	.75 mV/m	-3%
RMS, NE quadrant	.74 mV/m	.70 mV/m	-6%
1610 kHz			
RMS, all measurements	2.06 mV/m	1.80 mV/m	-10%
RMS, NE quadrant	1.84 mV/m	1.47 mV/m	-25%

From the data above it can be seen that the asymmetrical configuration caused some reduction in overall RMS field strength and a still greater reduction in the northeast quadrant, which is the quadrant devoid of ground radials in the asymmetrical case. However, it may also be noticed that these reductions are not significant at 530 kHz. They are more pronounced at 1610 kHz, but do not result in an unacceptable field strength even in the northeast quadrant. The conclusion is that symmetry in ground radial arrangement is not critical. This is of significance in a practical situation where the ground plane configuration may be constrained by the shape of the available land area or by buildings and other obstructions. Field strengths will be higher in the directions in which radials are extended, particularly at 1610 kHz.

The effect of length and number of ground radials has also been investigated by means of a free space mathematical model designated WRSMOM (see Report No. FHWA-RD-80-178, "Mathematical Analysis of Electromagnetic Radiators for Highway Advisory Radio," Vol. I, "Vertical Monopoles"). The model does not provide ground resistance, but does calculate antenna capacitance and radiation resistance. Model results show that with eight radials, capacitance does not increase with radial lengths greater than the monopole height. Radiation resistance increases rapidly up to radial lengths equal to monopole height, and very slowly as radial lengths are made longer. Data on numbers of relatively long radials (3.4 x monopole height) show a 21% increase in capacitance going from two to eight radials, a 4% increase going from eight to 16 radials, and only a 2% increase going from 16 to 32 radials. Radiation resistance varies very little above eight radials.

Based on the preceding measured and model data, the following recommendations can be made with respect to the design of a radial ground system for HAR monopoles.

1. Length: At least twice the monopole height.
2. Number: At least eight.
3. Material: No. 10 or 12 AWG bare solid copper wire has proved effective.
4. Configuration: Symmetrically arranged in a circle if practical. However, the pattern may be altered to fit space available without appreciable loss of coverage. For example, a "bow-tie" configuration might be used to fit a restricted highway right-of-way.
5. Burial: Burial to a depth of .5 m to .75 m is recommended both to protect from damage and to provide good earth contact. An alternative when concrete or asphalt pavement makes burial difficult is to drop the radials into shallow slots cut into the surface, and to connect the ends of the cable to ground rods driven into the earth.

Lightning Protection

A lightning discharge to a HAR monopole without protection will normally pass through the transmitter circuitry to reach ground. Even with protection there is no guarantee that damage will not occur. However, the liklihood can be reduced by the use of protection devices intended to conduct the lightning discharge to ground ahead of the transmitter. Two such devices have been used in HAR systems. One is a surge arrester which is a small, sealed, gas filled spark gap inserted in the antenna lead between antenna and transmitter. A third terminal, usually the metal case surrounding the device is securely grounded to the transmitter enclosure. The transmitter and antenna terminals of the arrester are connected by a solid conductor which is also connected to

one side of the spark gap. The other side of the gap is connected to ground. The gas provides a very high resistance path to ground under normal conditions. However, when hit by lightning the gas ionizes and creates a virtual short circuit to ground. When the lightning surge passes, the gas de-ionizes and normal operation resumes. Devices of this type are available from a number of radio equipment suppliers for under $50. An example is the Hy-Gain Electronics Corporation Model LA-1.

The other device is an air discharge gap which is used by the US Park Service and illustrated in Figure 22. It is formed by bending a standard 12.77 mm diameter copperweld ground rod and attaching it to the wooden support structure such that the pointed tip is 6 mm from the antenna surface. A lightning strike should cause the air to ionize forming a low resistance arc from antenna to ground. This method of protection is not considered as reliable as the use of a gas tube surge arrester since breakdown voltage is more difficult to predict and control.

Figure 22. Example of an Air Gap Lightning Arrester on a Vertical Monopole

Grounding is an important consideration in lightning protection. In the absence of water pipes or steel building frame, the National Electrical Code (NEC) specifies the use of 2.44 m ground rods (15.9mm-diameter steel or 12.7mm diameter non-ferrous) driven into the earth. The NEC permits a single rod if it is measured to have less than 25 ohms resistance, otherwise several rods spaced 1.8 m apart and connected in parallel should be used. It is recommended that a rod for this purpose be driven into the ground at the base of the antenna support structure and connected in common with the antenna ground system. The surge arrester, air discharge gap or other device should be connected directly to the rod by No. 6 AWG or larger solid copper wire.

CHAPTER 7

MONOPOLE ANTENNA DESIGN OPTIONS

Although commercially available HAR monopoles now offered will provide satisfactory performance at 1610 kHz, this is not the case at 530 kHz. However, there are various options available to the designer for achieving good performance at 530 kHz. These are discussed in this chapter.

Commercially Available Antennas

There are a number of commercially available HAR monopole antennas which may be obtained at reasonable cost. A list of these with their principal characteristics is given in Table 6. All have some form of inductive loading built into the antenna structure itself. Final tuning is obtained in some cases by adjustments to a base loading inductor, and in another by changing the length of an adjustable telescoping top section. Instructions for their installation are provided by the suppliers. The Morad antennas are designed to be installed without the use of sophisticated instrumentation. However, a standard field strength meter is a useful instrument when making matching adjustments and is required in any case for demonstrating compliance with FCC limitations on field strength. Another highly desirable instrument is an RF impedance (or admittance) bridge for impedance measurements. Altough not required to comply with instructions furnished by Morad, an impedance bridge or some equivalent instrumentation is the only way to assure a good match between an antenna system and transmitter.

Table 6. Commercially Available HAR Monopole Antennas.

Monopole Type	Manufacturer and Model	Antenna's Physical Characteristics	Frequency (kHz)	Cost[b] (dollars)	Comments
Base loaded	34-363	4 m fiberglass rod	530 or 1610 depending on ferrite loading coil at the base of the antenna	120	For each of these antennas the manufacturer supplies standard mounting flanges and installation guidelines. The manufacturer also provides grounding wire, rods, and a suggested grounding system. Both may be mounted on top of transmitter enclosure.
	34-369 Travelers Information Service, Inc.	4.3 m aluminum base section and a 2.7 m fiberglass section		125	
	34-370 Travelers Information Service, Inc.	10.7 m two section fiberglass rod self supporting with eight 33 m ground radials	Same as above	900	Same as above, except requires mounting on concrete pad.
Continuously loaded (helical)	Anixter, Mark HW-SPEC-8	2.44 m fiberglass rod 12.7 mm diameter. Wound along the entire length with No. 16 AWG copper wire.	1610	less than 100	This antenna is a special order. Currently, a 530 kHz continuously loaded monopole is not available.
Inductively top loaded	MORAD[a] SF 1610	3.75 m length 25.4 mm diameter aluminum mast. One-half meter in length air core inductor atop the mast.	1610	104	Predominant monopole antenna used on HAR and NPS stations.
Center loaded	MORAD[a] SF-530A	6.62 m length 25.4 mm diameter aluminum mast. One metre in length air core inductor centrally affixed to antenn's mast.	530	190	This antenna supersedes the SF530.

[a]MORAD antennas are distributed through Audio Sine, Inc. Each requires onsite tuning to the ground plane and geographical surroundings. Both MORAD antennas are tuned with an aluminum rod through the air core inductor. An RF impedance bridge should be used to tune these antennas.

[b]1980 prices, including loading or matching networks.

Tables 7 and 8 show results obtained with actual installations of Morad SF 530 (530kHz) and Morad SF 1610 (1610kHz) antennas. All are mounted near ground level in accordance with the manufacturers' instructions. Earth conductivity and ground system details are given since these parameters decidely affect measured performance. It should be noted that the maximum permissible field strength of 2 mV/m at 1.5 km is generally attainable at 1610 kHz. However, this is not the case for 530 kHz.

It has been found that antenna efficiency can be considerably increased by elevating above the terrain, using either a wooden or metallic supporting structure. For example, the Morad SF530 and SF 1610 antennas used for the measurements shown in Figures 18 and 19 were re-mounted on a 76 mm diameter aluminum pipe such that the antenna bases were 7.6 m above ground, as shown in Figure 23. The results of measurements made with the elevated antennas were:

Frequency	F.S. at 1.5 km (mV/m)	Improvement over Un-elevated Antenna
530kHz	1.4	40%
1610kHz	4.0*	60%

In another instance, the antennas at the Gatlinburg sites, (numbers 1, 2 and 4 shown in Table 7) were elevated on wooden utility poles to the maximum height permitted by the FCC. Transmitter enclosures were mounted near the bases of the poles and connected to the antennas by No. 8 AWC solid copper antenna leads. The configuration is similar to that shown in Figure 23 except for the substitution of a wooden pole for the aluminum mast. The following improvements in RMS field strengths were achieved at 530 kHz.

---

*Exceeds FCC limits.

Table 7. Performance of MORAD SF 530A Monopole.

Location	Type Ground System	σ (mS/m)	F.S. at 1.5 km (mV/m)[a]	Efficiency (%)
Richmond, VA	2.4 m Ground Rod	1	0.6	0.16
Gatlinburg, TN # 1	6 - 30 m Radials	1	0.47	0.1
Gatlinburg, TN # 2	6 - 30 m Radials	1	0.8	0.3
Gatlinburg, TN # 3	6 - 30 m Radials	1	0.8	0.3
Gatlinburg, TN # 4	6 - 30 m Radials	0.5	0.5	0.18
Gainesville, VA	8 - 13.7 m Radials	1	1.0	0.46

[a]For 10W in.

Table 8. Performance of the MORAD SF 1610 Monpole.

Location	Type Ground System	σ (mS/m)	F.S. at 1.5 km (mV/m)[b]	Efficiency (%)
Devil's Tower, WY	6 - 18.3 Radials	10	2.2	1.6
Davenport, IO	10 - 9.1 m Radials	10	2.3	1.6
Avoca, IO	10 - 9.1 m Radials	10	2.1	1.4
Houston, TX	4 - 7.6 m Radials	15[a]	0.7	0.14
Grand Canyon,AZ	6 - 12.2 m Radials Plus Underground Tank	0.5	0.3	0.33
Gainesville, VA	8 - 13.7 m Radials	2	2.4	6.8

[a]Based on FCC value for area — not reliable.
[b]For 10W in.

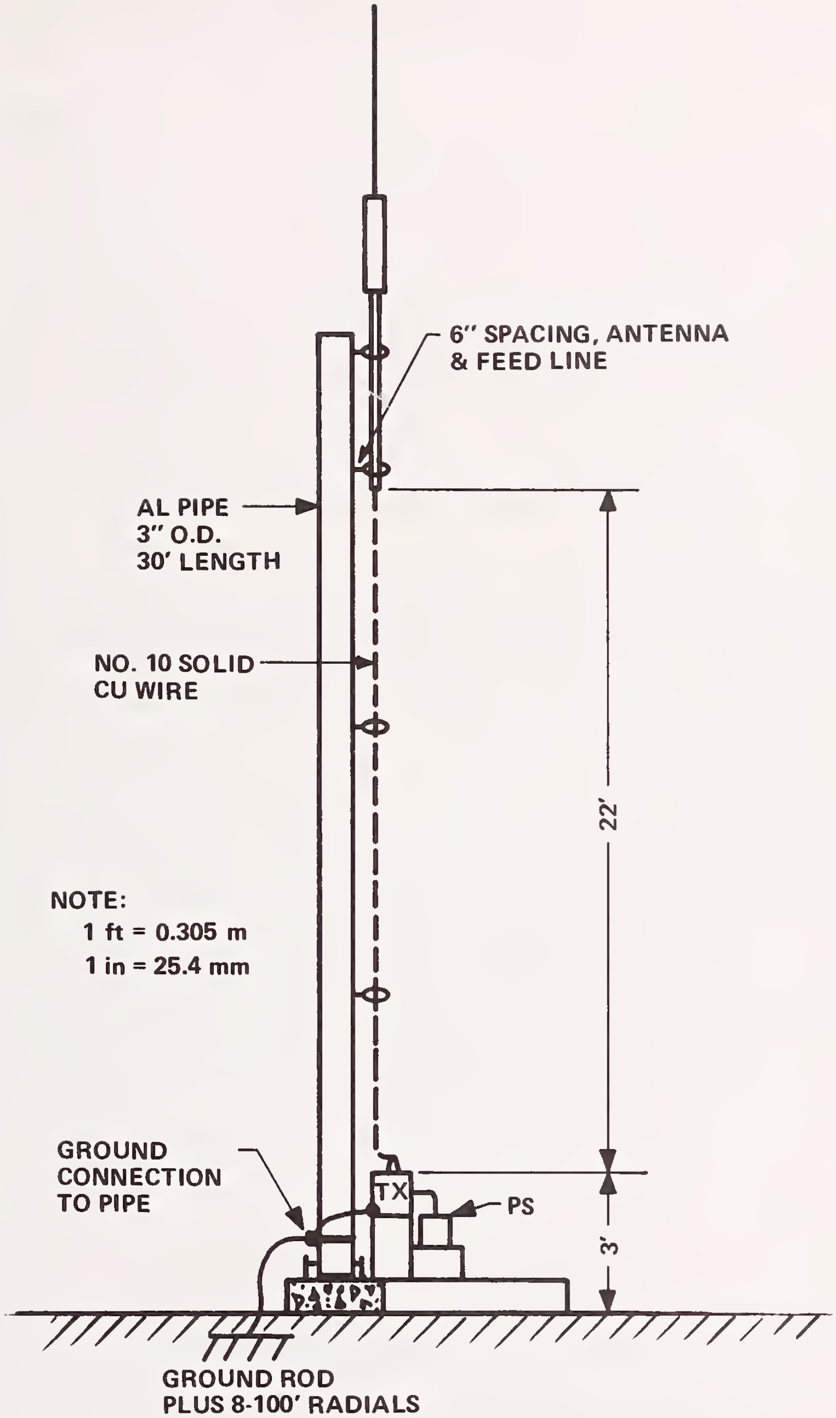


Figure 23. Morad SF 530 and SF 1610 Mounting Details, Aluminum Mast Support.

	F.S. at 1.5 km (mV/m)	Improvements over Un-elevated Antenna
Antenna #1	1.2	160%
Antenna #2	1.6	98%
Antenna #4	1.2	144%

Appendix D shows design details of a wooden antenna support structure recommended by the US Park Service for use in the National Parks. This structure requires a 12.2 m utility pole, 10.7 m or which extends above ground.

The tuning of Morad antennas, particularly if mounted on an elevated support structure, poses a particular problem. Matching is accomplished by adjusting the top section which "telescopes" in and out of the section below. Tuning this section requires either that the antenna be taken down and raised for each adjustment, or that a bucket crane be utilized. A good match usually requires a number of minor adjustments which can be time consuming under the above conditions. One technique that has been found useful involves making coarse adjustments and deliberately leaving the input reactance at roughly 100 ohms inductive. Final adjustments are then made at ground level by inserting the appropriate size capacitor in series between transmitter and antenna lead. A set of varying sizes of ceramic capacitors is useful for finding the appropriate size (i.e., that which completely nulls out the reactive component of input impedance.) The residual reactance which is to be nulled out by this method should not exceed 100 to 200 ohms. Otherwise, the high reactive voltages generated could puncture the tuning capacitor.

Custom Design of Vertical Monopoles

An alternative to the purchase of a commercially available antenna would be one custom designed for the application. Given the relatively low cost of HAR antennas on the market, the time and effort of custom design is not

justified or recommended at 1610kHz. However, there may be situations where greater efficiency is desired at 530kHz. The emphasis in this section is on design of such antennas.

The simplest design is a straight, base-loaded vertical monopole. The vertical section can consist of any vertically oriented conductor, such as a rod, whip or tube. The efficiency will be a function of the radiation resistance which, for electrically short antennas, varies as the square of the height to wavelength ratio. With a height limit of 15 m, efficiencies obtainable at 530 kHz are very poor. This design is therefore not recommended for HAR use. However, a variation of this design obtained by adding capacitive top loading has shown considerable improvement over a straight monopole.

An investigation of a capacitive "top hat" consisting of a circular array of eight horizontal radials each 12.7 mm in diameter and 1.52 m long was made using the WRSMOM free space mathematical model previously referred to. Computations were made for a 76.2 mm diameter vertical section with heights of 4.6 m, 9.1 m and 13.7 m. The ground plane was assumed to consist of a circular array of eight 13.7 m radials. The results comparing capacitance and radiation resistance with and without top loading are shown in Figures 24 and 25. Figure 24 also shows a comparison of field data made with experimental antenna structures of the same dimensions fabricated with aluminum pipe. A photograph of an experimental monopole with top hat is shown in Appendix E.

In Figure 25 it can be seen that the radiation resistance is more than doubled by the addition of top loading to relatively short monopoles. As the height increases, the improvement is less but still significant. The improvement in capacitance seen in Figure 25 also has a beneficial effect in that it requires a smaller matching inductance with resulting lower losses. The net

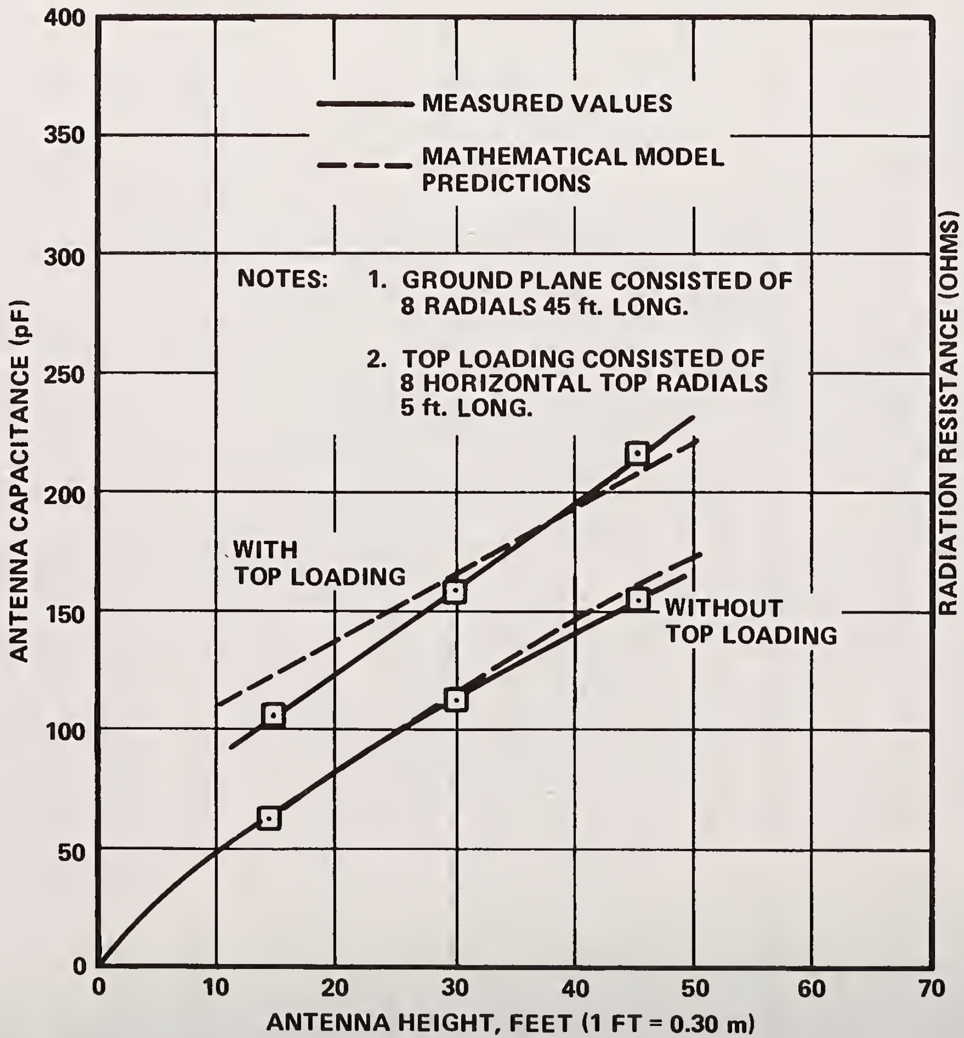


Figure 24. Capacitance of 76 mm Diameter Monopole - 530 kHz.

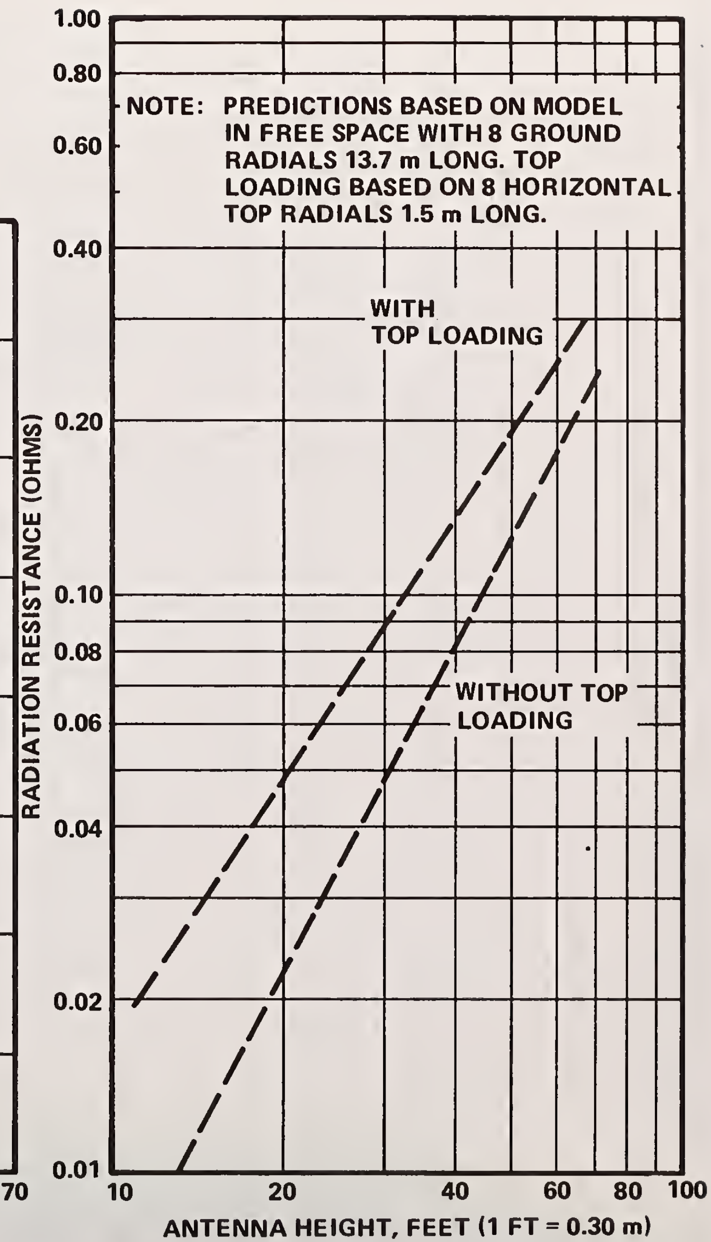


Figure 25. Mathematical Model Predictions of Radiation Resistance of 76 mm Diameter Monopole - 530 kHz.

effect of improved antenna capacitance and radiation resistance can be seen in the measured data shown in Table 9. Comparisons are made in the table of the efficiency and field strength at 1.5 km (at 10 watts input) for monopoles with and without top loading at both 530 kHz and 1610 kHz. The Morad SF530 and SF1610 results are shown for reference. The table shows that the 13.7 m top loaded monopole is twice as efficient as the SF 530, and could be made more efficient with a larger top hat. The table also shows the efficiencies that can be achieved at 1610 kHz. At this frequency, however, inexpensive commercial antennas are quite capable of meeting and exceeding the FCC limit.

Critical to custom monopole antenna design is the design of the matching network. Two useful designs are shown in Figures 26 and 27, the first utilizing a series inductance and the second a shunt inductance.

Figures 26 and 27 take coil losses into account by assignment of a value of Qm to the matching inductor. The figures also give exact expressions for matching network efficiency, which makes it possible to compare the relative efficiency of the two approaches. It can be shown that for all values of capacitive antenna reactance typical of short monopoles, the use of a series inductance is more efficient. The following example will illustrate. A value of 20 ohms for the antenna resistance (typical of HAR ground systems measured) and of 100 for Qm is assumed.

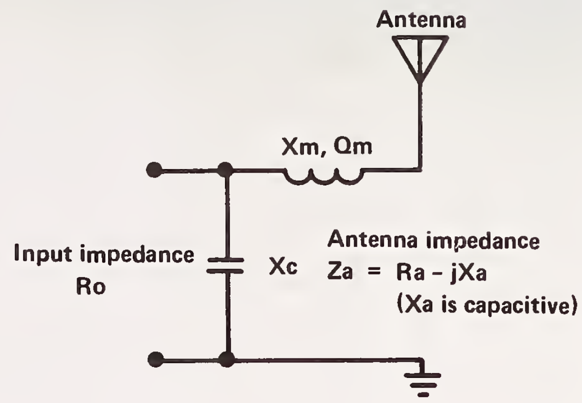
Antenna Reactance (ohms capacitive)	Efficiency, Series Inductor (%)	Efficiency, Shunt Inductor (%)
100	94	92
500	79	70
1000	66	53
2000	50	33
3000	40	22
4000	33	16

Table 9. Performance of Experimental Monopole Antennas of Various Heights.

	σ (mS/m)	F.S. at 1.5 km (mV/m)	Efficiency (%)
530 kHz			
Antenna			
4.6 m monopole	1	0.17	0.013
4.6 m monpole with top loading	1	0.29	0.038
9.1 m monopole	1	0.25	0.029
9.1 m monopole with top loading	1	0.67	0.20
13.7 m monpole	1	1.2	0.60
13.7 monopole with top loading	1	1.5	1.0
MORAD SF 530A	1	1.0	0.46
1610 kHz			
Antenna			
4.6 m monopole	2	0.58	0.39
4.6 m monopole with top loading	2	2.3	6.1
9.1 m monopole	2	2.7	8.4
9.1 m monopole with top loading	2	4.3	21.4
13.7 m monopole	2	5.0	29.2
13.7 monopole with top loading	2	5.1	30.0
MORAD SF 1610	2	2.4	6.8

Notes:

1. Monopoles constructed of 7.6 cm aluminum pipe. Ground planes consisted of 8 - 13.7 m ground radials. Top loading consisted of 8 - 1.5 m radials at top of antenna.
2. Field strengths (F.S.) for 10 watts power in.
3. Field strength values exceeding 2 mV/m at 1.5 kM not permitted by the FCC.



If $Qm \gg 1$,

$$Xm \simeq Xa - (Ro - 2Ra)/2\,Qm + \sqrt{Ra\,(Ro - Ra) + Xa\,(Ro - 2Ra)/Qm + (Ro/2Qm)^2}$$

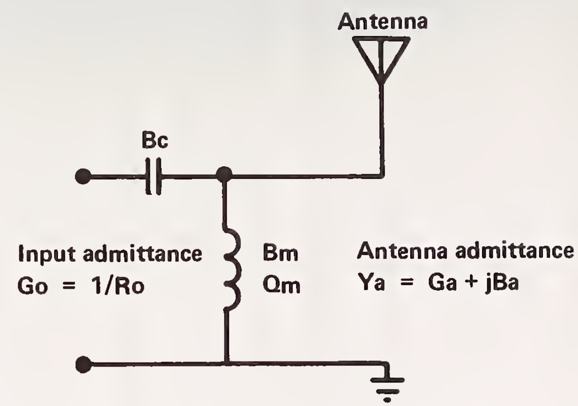
Inductance = $Xm/2\pi f$ millihenries (f in kHz)

$Xc = Xm - Xa + (Ra + Xm/Q)^2/(Xm - Xa)$

Capacitance = $10^9/2\pi f Xc$ picofarads (f in kHz)

Network efficiency = $QmRa/(Xm + QmRa)$

Figure 26. Series Inductor Matching Network For Short Monopole.



If antenna impedance is measured,

$Ga = Ra/(Ra^2 + Xa^2) \simeq Ra/Xa^2 \quad (Xa \gg Ra)$

$Ba = Xa/(Ra^2 + Xa^2) \simeq 1/Xa \quad (Xa \gg Ra)$

If $Qm \gg 1$,

$$Bm \simeq Ba - (Go - 2Ga)/2\,Qm + \sqrt{Ga(Go - Ga) + Ba/(Go - 2Ga)/Qm + Go/2Qm)^2}$$

Inductance = $1/2\,\pi f Bm$ millihenries (f in kHz)

$Bc = Bm - Ba + (Ga + Bm/Q)^2/(Bm - Ba)$

Capacitance = $10^9\,Bc/2\pi f$ picofarads (f in kHz)

Network efficiency = $Qm\,Ga/(Bm + Qm\,Ga)$

Figure 27. Shunt Inductor Matching Network for Short Monopole.

The above table illustrates not only the greater efficiency of a series matching inductor, but also the very high losses that can occur in the matching network of either type when it is necessary to match out very high antenna reactances.

The design and adjustment of the matching network requires the use of an impedance bridge or an admittance bridge. An impedance bridge, such as the General Radio Model 1606, indicates equivalent series resistance and reactance in ohms. An admittance bridge, such as the Wayne Kerr B202 indicates equivalent shunt conductance in millisiemens (mS) and shunt capacitance in picofarads. (Millisiemens is the SI term for the older "millimhos"). Either type of bridge may be used with appropriate conversions when required. The following procedures are recommended.

1. Measure the antenna impedance ($Za = Ra - jXa$) or admittance ($Ya = Ga + jBa$) after installation.

2. Calculate the values of the matching network components from Figure 21 or 22 as appropriate.

3. Select or construct an inductor of the appropriate size. Check the size with the bridge or a Q-meter. Air-core inductors are recommended.

   Note: Ferrite cores have generally proved unsatisfactory in HAR applications because of high losses and instability with changes in temperature and power level. Some of these disadvantages can be overcome by the use of pot cores with air gaps. However, these require careful design and a high degree of design expertise. Because of sensitivity to power level, final alignment must always be made at rated input power.

4. Connect the inductor to the antenna base. Re-measure the antenna input impedance or admittance with the inductor in place. In the case of the shunt inductor the real component of impedance should measure 50 ohms. For the series inductor the real component of admittance should measure 20 mS (which will not measure 50 ohms on an impedance bridge if there is a reactive component of admittance). If the desired value of resistance or conductance is not obtained, adjustments to the inductor is required. This may require adding or removing turns.
5. Add the capacitor to the network. The input impedance should now measure close to 50 ohms in either case (20 mS if the admittance bridge is used). Make adjustment in capacitor size if necessary to completely null out any residual reactance or susceptance. A final value of non-reactive input impedance between 40 to 60 ohms is acceptable.

One other approach to the custom design of monopoles is the use of the normal mode helical antenna. Helical antennas can be wound to be self resonant and may in many cases be used with no external matching network. It may, in fact, be viewed as a short monopole with a matching inductance distributed along its entire length. A helical antenna may be driven from the base (series fed) or it may be driven from a tap point above the base (shunt fed) with the base grounded. As does any monopole antenna, the helical requires a good ground system. If the antenna is resonant, the input impedance will be non-reactive at either base or shunt tap point. The resistive component of the impedance varies with the tap point such that the tap point may be adjusted if necessary to find the exact 50 ohm location. The resistance at the base

cannot be varied (without adding an external matching network). However, in experimental tests with antennas wound on 114 mm diameter plastic pipe the base resistance typically fell in the range of 30 to 40 ohms, which can be driven from a 50 ohm source with less than 10% power loss.

Design parameters for helical antennas are given for various heights and diameters in Appendix F. To use the appendix, the designer must choose the desired height, diameter and operating frequency. For an AWG of 14, the tables give the wire length, turns per unit length of antenna height, turns spacing, calculated efficiency over an ideal ground plane, and the tap point (height above the antenna base) calculated to have an impedance of 50 ohms when the antenna is shunt fed.

Table 10 shows the results of a number of experimental helical antennas wound on 114 mm diameter PVC pipe. A photograph of an experimental helical may be seen in Appendix E.

Table 10. Performance of Three Helical Antennas at 530 kHz.

Antenna	Ground System	σ (mS/m)	F.S. at 1.5 km (mV/m)	Efficiency (%)
4.6 m, shunt fed	8 - 13.7 m Radials	1	0.44	0.09
13.7 m, series fed	8 - 13.7 m Radials	1	1.9	1.9
13.7 m, series fed	8 - 27.4 m Radials	1	2.2	2.2

Notes:

1. Helical antennas wound on 114 mm diameter PVC pipe.
2. Field strength (F.S.) measurements for 10 watts power in.

In practice it has been found very difficult to construct a helical antenna to be exactly resonant at the desired frequency without subsequent modifications. Another approach is to design the antenna to be slightly below resonance. The input impedance will then have an inductive component if shunt fed (or a capacitive component if series fed). With the aid of an impedance bridge, a tap point having a resistive component of 50 ohms is located. A series capacitor of the proper value is then added to null out the inductive reactance. The bridge should again be used to make a final check to assure that a non-reactive input impedance of 50 ohms results.

Directional Arrays

Directional arrays of vertically polarized antennas are permitted by the FCC Rules for HAR stations. However, the design of directional arrays specifically for HAR applications remains a relatively unexplored field. The same limits apply to arrays as to single unit monopole antennas: (1) a field strength of 2 mV/m at 1.5 km may not be exceeded, (2) not more than 10 watts RF input power may be used and (3) the heights of antennas in the array may not exceed 15 m. As indicated, a directional array cannot be used to increase field strength in any direction above the 2 mV/m at 1.5 km limit. However, directional arrays may well prove useful as a means of reducing the potential for interference by reducing radiation in directions where radiation is not desired.

Arrays of HAR monopoles should behave as arrays of any other antennas. Possible array designs may be found, for example, in Chapter 9 of the National Association of Broadcasters (NAB) Engineering Handbook. There is, however, one important limitation in the choice of available designs. Directional

patterns are usually specified in the "far field" of the array, which applies only when the distance from the array is large compared to the greatest dimension of the array itself. The designer should therefore avoid choosing antenna spacings that are large relative to the distances at which he expects the directivity of the array to be effective.

A Two-Element Array Design

The two-element array design presented in this section has been successfully fabricated and tested at 530kHz. It represents a simple and practical approach to producing a cardiod pattern. It has a potential use in situations where it is important to substantially reduce radiation in a given direction while maintaining radio coverage in other directions.

The array made use of two Morad SF530 antennas separated 1/8 wavelength (141 m), and which were fed from a common 10 watt transmitter. A precisely cut length of coaxial cable was used to produce a 135 degree phase lag in one antenna. Details of the array are shown in Figure 28. Ideally, the array should produce a cardiod pattern with a null in the direction of the No. 1 (leading) antenna.

The two antennas of the array were mounted on wooden stakes driven into the ground such that their bases were approximately 0.6 m above ground. Seven ground radials consisting of 30 m of AWG 12 copper wire and a 12.7 mm copper strap were laid out radially from each antenna with the copper strap directly connecting the two ground systems (See Figure 29). At the antenna bases, the ground radials and the copper strap were connected to a copper wire circle ring approximately 0.3 m in diameter. At the end of each ground wire, a 0.6 m copper ground rod was hammered into the earth and soldered to the ground wire.

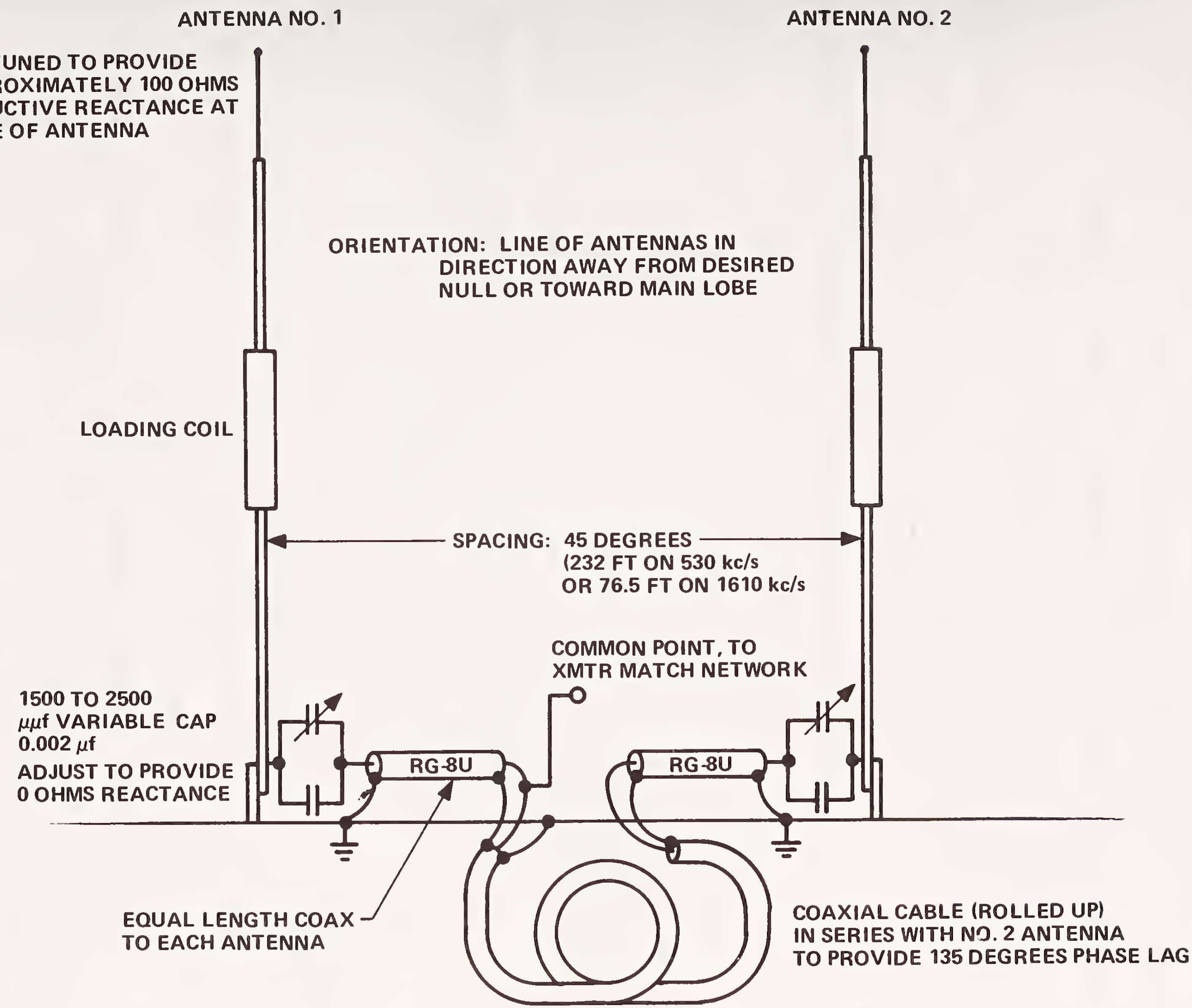


Figure 28. Construction Details of Cardioid Directional Antenna.

The method used to initially tune these antennas, which is also applicable for the single antenna installation, was to measure the impedance of the antenna at its base with an impedance bridge. Then the tip of the antenna was adjusted to provide approximately 100 ohms of inductive reactance at the base of the antenna, following which a series capacitor was used to tune out the reactance. The advantage of using this method is that it is not necessary to raise and lower the antenna many times in order to make repeated adjustments on the telescoping top section. This series tuning arrangement also provides an efficient method of fine tuning the two antennas when they are operated as a directional array, because they tend to interact to a degree.

For the purposes of fine tuning the antenna array, two simple resistance bridges were built. The wiring diagram is shown in Figure 30. Final tune-up of the directional array was accomplished by inserting the two resistance bridges in each antenna base feed and activating the transmitter. The series tuning capacitors were then readjusted to re-tune each antenna to resonance. When this was done, the transmitter was turned off and the bridges removed.

Figure 31 shows the phase shift network and the two feed lines joined at the common point. An "L" type network was inserted at the input to the common point from the transmitter. Its purpose was to match the 25 ohm resistance at the common point (resulting from the connection of two 50 ohm transmission lines in parallel) to the 50 ohm transmitter impedance.

One disadvantage of this method of splitting the transmitter power between the two antennas is that the antennas are not isolated from each other. Any attempt to re-tune one will interact with the other. This can be avoided by the use of a hybrid junction, such as the Merrimac HJM-1/25457. Such devices suitable for 530 and 1610 kHz sell for about $200 each.

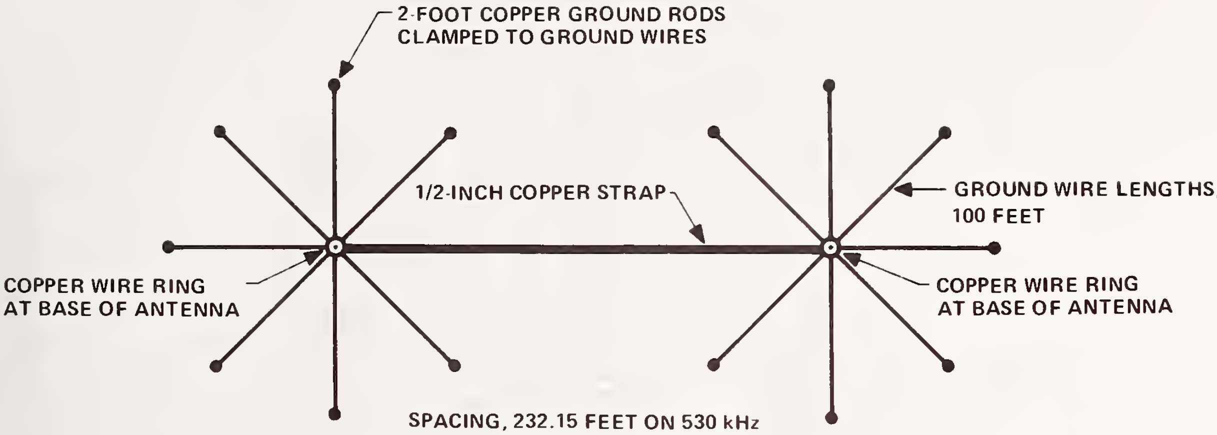
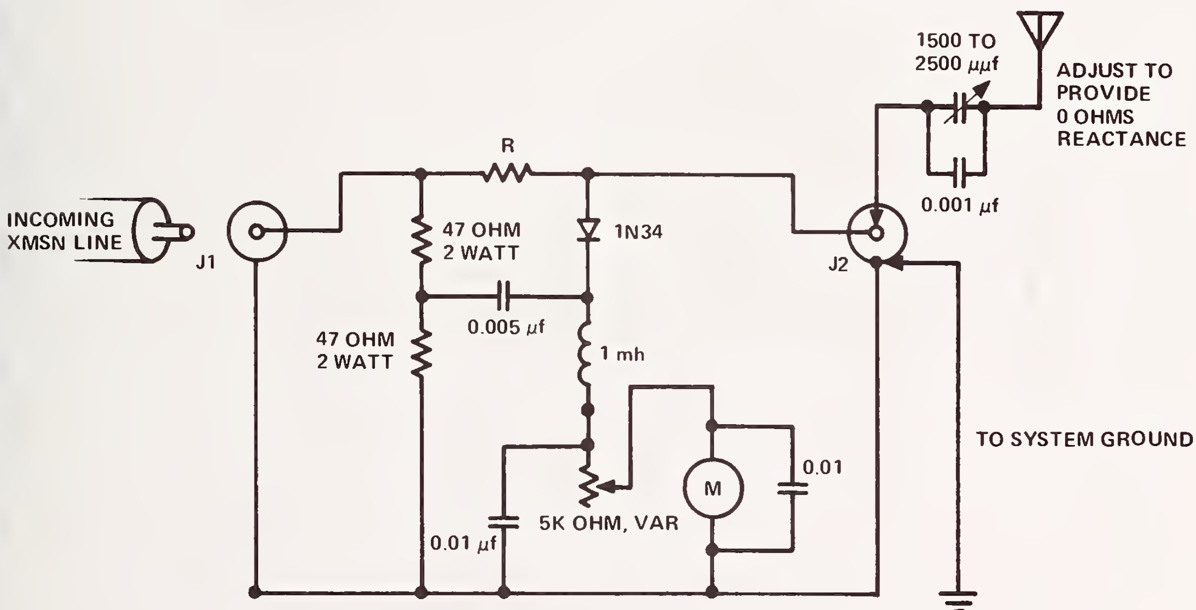


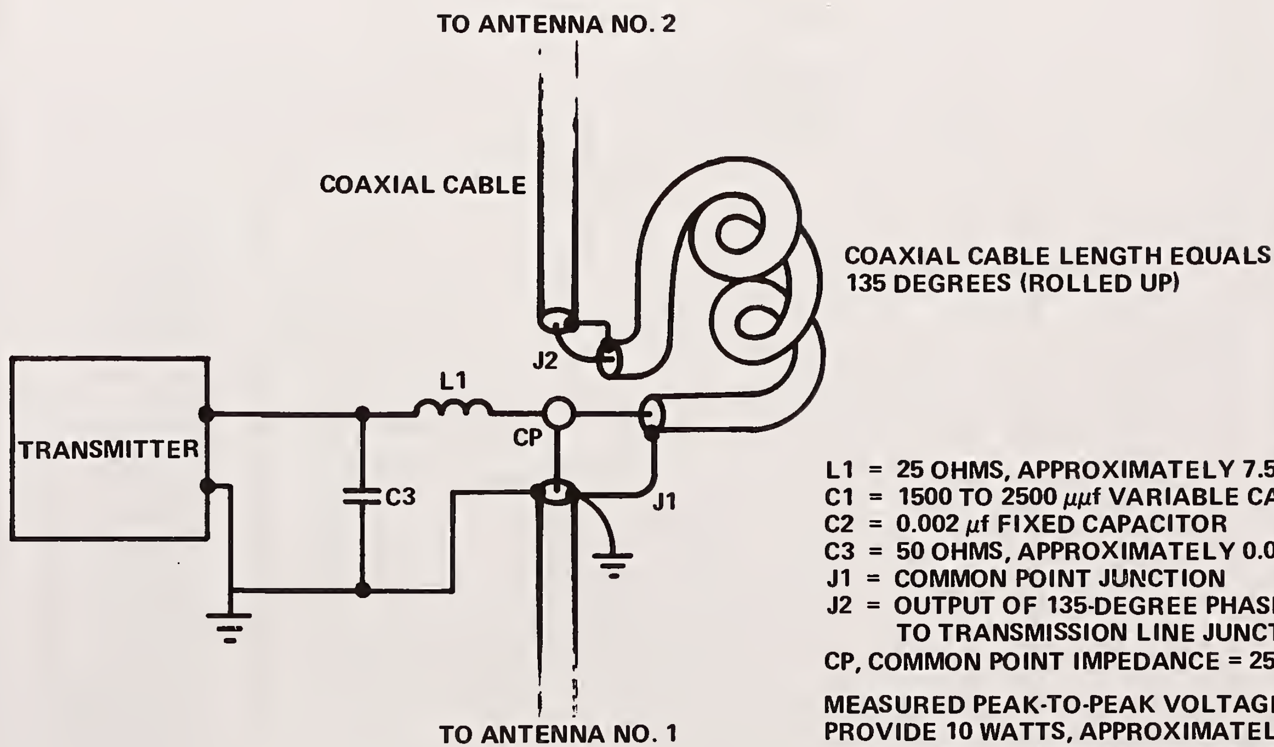
Figure 29. Directional Array Ground System.



R IS SET EQUAL TO ANTENNA RESISTIVE COMPONENT. IN THIS CASE' NO. 2 ANTENNA MEASURED 50 OHMS, THEREFORE, R IS 50 OHMS, 2 WATTS FOR THE NO. 2 ANTENNA. AT THE NO. 1 ANTENNA, THE BASE RESISTANCE MEASURED 63 OHMS, THEREFORE, R IS 63 OHMS.

M IS A 0-TO-1 MILLIAMMETER

Figure 30. Resistance Bridge Used at each Antenna to Tune the System to Resonance.



L1 = 25 OHMS, APPROXIMATELY 7.5 μh ON 530 kc/s
C1 = 1500 TO 2500 $\mu\mu$f VARIABLE CAPACITOR, MICA
C2 = 0.002 μf FIXED CAPACITOR
C3 = 50 OHMS, APPROXIMATELY 0.006 μf ON 530 kc/s
J1 = COMMON POINT JUNCTION
J2 = OUTPUT OF 135-DEGREE PHASE SHIFT CABLE TO TRANSMISSION LINE JUNCTION
CP, COMMON POINT IMPEDANCE = 25 + j0 OHMS

MEASURED PEAK-TO-PEAK VOLTAGE HERE TO PROVIDE 10 WATTS, APPROXIMATELY 44.7 VOLTS PEAK TO PEAK ON OSCILLOSCOPE OR APPROX. 0.63 AMPS RMS WITH AN RF AMMETER FOR 25 OHMS.

Figure 31. Matching Network to Match 25-Ohm Common Point to 50-Ohm Transmitter Output.

Field strength measurements were taken along eight radials measured from the center of the array. The inverse distance fields derived from these measurements are compared with the theoretical cardiod pattern for the array in Figure 32.

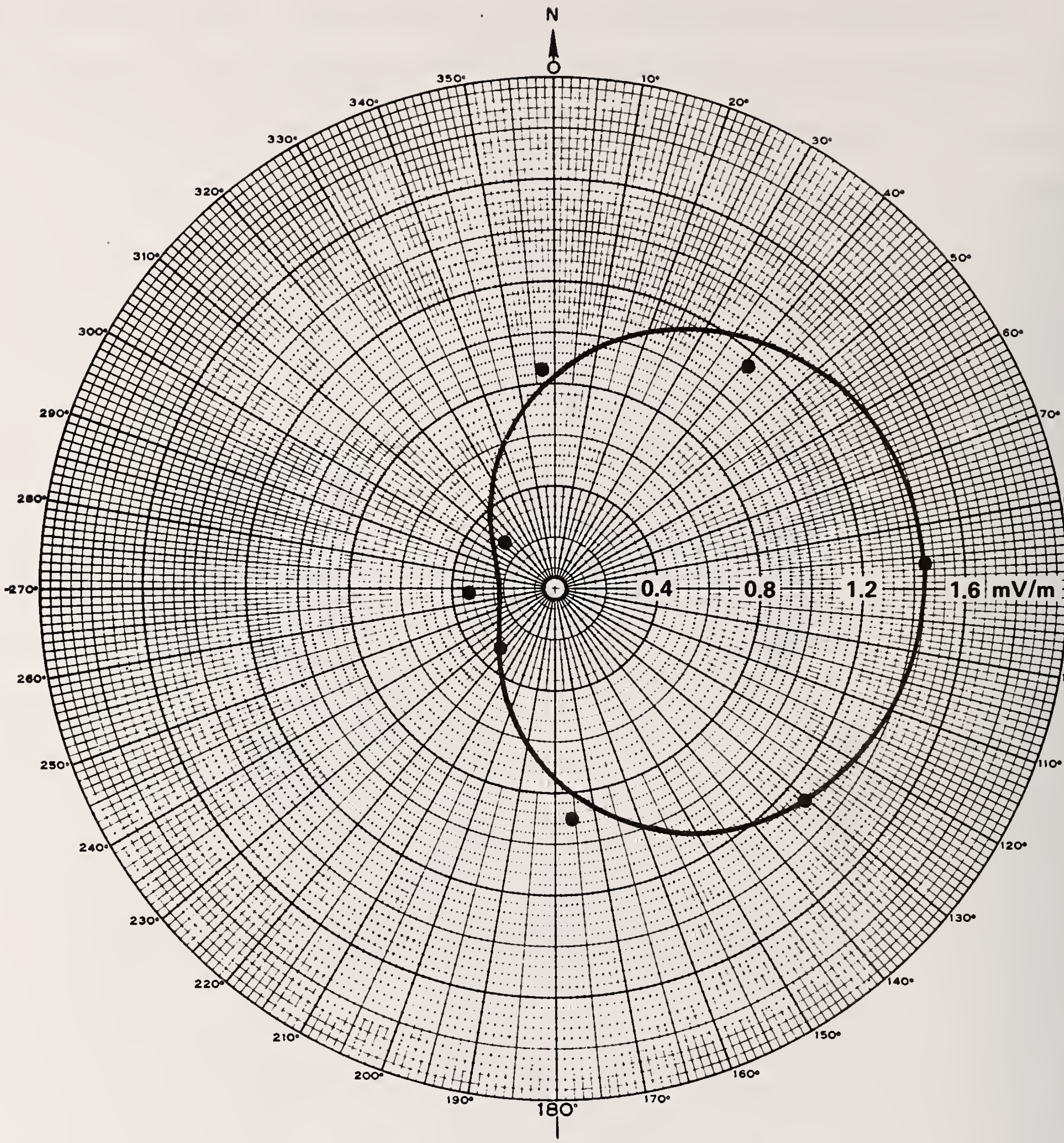


Figure 32. Inverse Distance Fields at 1.6 km (1 Mile) Compared with Theoretical Pattern of Two-Element Directional Array at 530 kHz.

CHAPTER 8

CABLE ANTENNAS

Cable antennas are transmission lines so designed that fields are not totally confined. Reception by car radios is chiefly a near-field phenomenom and consequently, is confined to the near proximity of the cable.

Under FCC rules, cable antennas may be as long as 3 km and may be fed with up to 50 watts of RF power provided the 2 mV/m at 60 m limit is not exceeded. A cable antenna may be fed from either end, or as is often done, from the center through a power splitter. The undriven end (or ends) of a cable should be terminated in its characteristic impedance. Because the field strength of a cable antenna drops off very rapidly beyond the end of the cable, two independent systems on the same frequency can be located almost end-to-end without overlapping interference between the two. Where this is done, the FCC will permit a short length of transitional cable between the two systems to be excited with an unmodulated carrier. This transitional field will keep vehicular receivers quiet (through AGC action) as the receivers pass from the coverage of one HAR system to the other.

Several techniques have been employed in the design of "leaky feeder" cables for use in HAR and other types of communication systems. Four designs are illustrated in Figure 33. Three of these are seen to be essentially coaxial cables with discontinuities or interruptions in the outer conductor. A fourth is seen to be a spiral conducting ribbon around an inner grounded sheath. A third conductor, inside the ground sheath, forms a coaxial cable

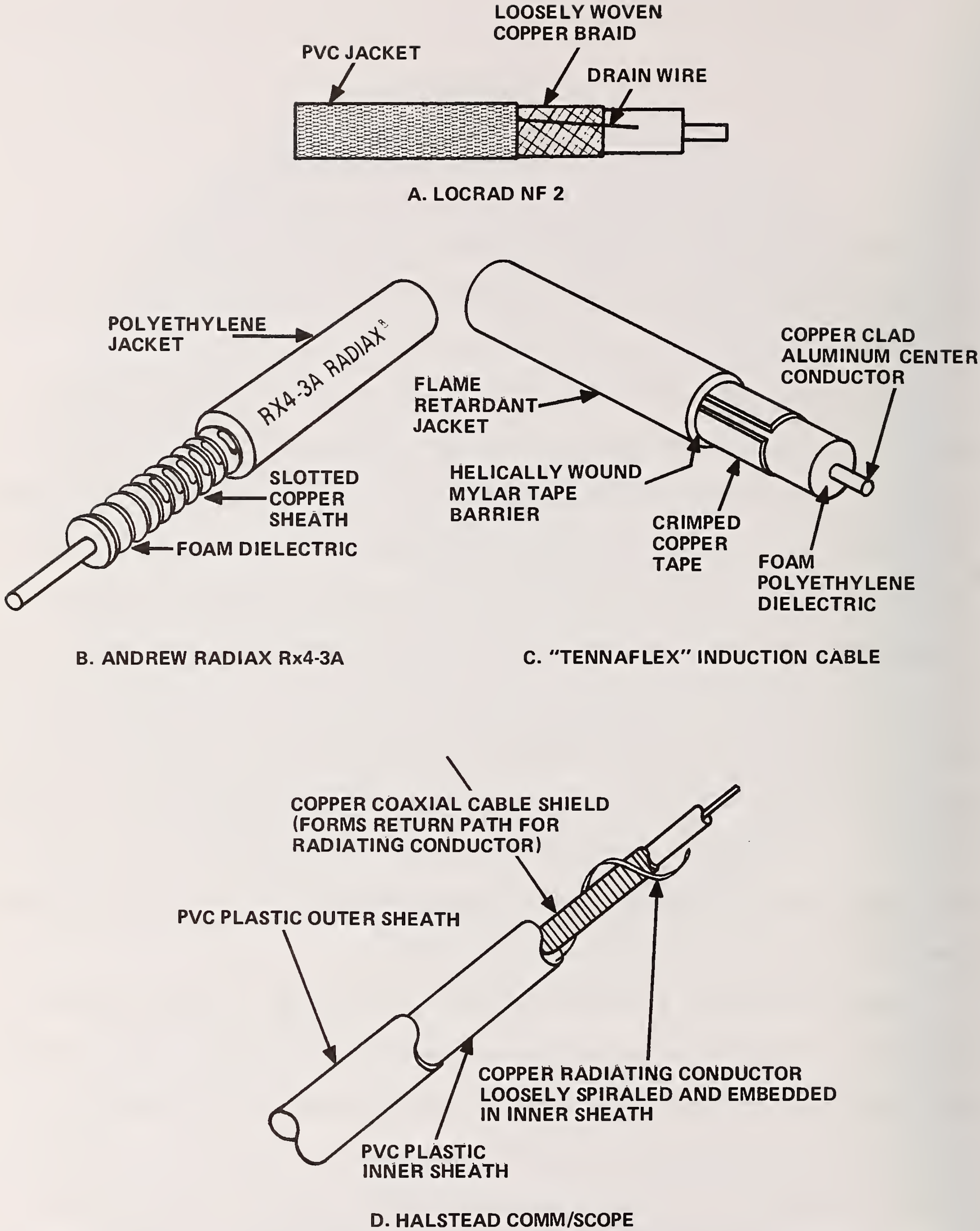


Figure 33. Commercially Available Cable Antenna Types.

with the ground sheath, but this plays no part in the radiation performance of the cable.

Cable antennas are normally buried along the roadway served, either in the right shoulder or along the median strip. Burial is not a requirement, but is done primarily to protect the cable from damage or vandalism. It may equally well be attached to guardrails, structural members of bridges, or the walls of tunnels and sunken roadways.

Commercially Available Cable Antennas

Characteristics of four commercially available cables suitable for use in HAR systems are given in Table 11. These cables correspond with the four types illustrated in Figure 33.

Cable Antenna Configurations

A cable antenna may be driven from one end or through a power splitter in the center. These configurations are shown in Figure 34. If the cable attenuation is high, the field strength at the load end of a long cable will be considerably less than at the transmitter end. The advantage of feeding a long cable from the center, although the power input to each half is reduced by 3 dB, is that the variation in average field strength from one end to the other is reduced. Further, if the total attenuation of the entire length of cable is greater than 6 dB, the minimum field strength along the cable (occurring at the extreme ends) is actually increased over what would be achieved by feeding the cable from one end.

A hybrid junction, such as the Merrimac HJM-1/25457 referenced in connection with the design of a directional array, will also serve very well as a splitter in a cable antenna system.

Table 11. Commercially Available Cable Antennas.

Manufacturer/ Model No.	Nominal Impedance (ohms)	Attenuation[a] (dB at F kHz per 100 m)	Diameter (mm)	Weight (kg/m)	Maximum Bending Radius (mm)	Cost[b] ($ per m)	General Comments
Andrew Radiax RX4-3A	50	0.22 at 0.530 0.41 at 1610	15.8	0.238	254	4.80	1. Provides connectors, terminating loads, splicing kits, and hangers for RADIAX. 2. Cable attenuation from direct burial is minimal.
Halstead Comm/Scope	70	0.50 at 530 0.88 at 1610	17.5	0.262	178	2.92	1. Sold only as part of a HALSTEAD system. 2. Cable attenuation from direct, burial is minimal.
Cablewave Systems Systems, Inc.	50	N/A	15.2	0.21	127	N/A	1. Cable has not been used for HAR at this time. 2. Provides connectors, hangers, and splicing kits for Tenna/Flex. 3. Production for this line of cable has been temporarily discontinued.
Locrad, Inc. NF-2	50	0.58 at 530 0.94 at 1610	12.7	N/A	N/A	2.72	Comes with loads and connectors installed. Replaces NF-1.

[a]Based on measurements of cable buried 46 cm along Dulles Airport Access Highway, June 1979.

[b]Based on 1978 quotes for 1829 m (6,000 feet). Suppliers will often negotiate price on large purchases.

N/A: Not Available.

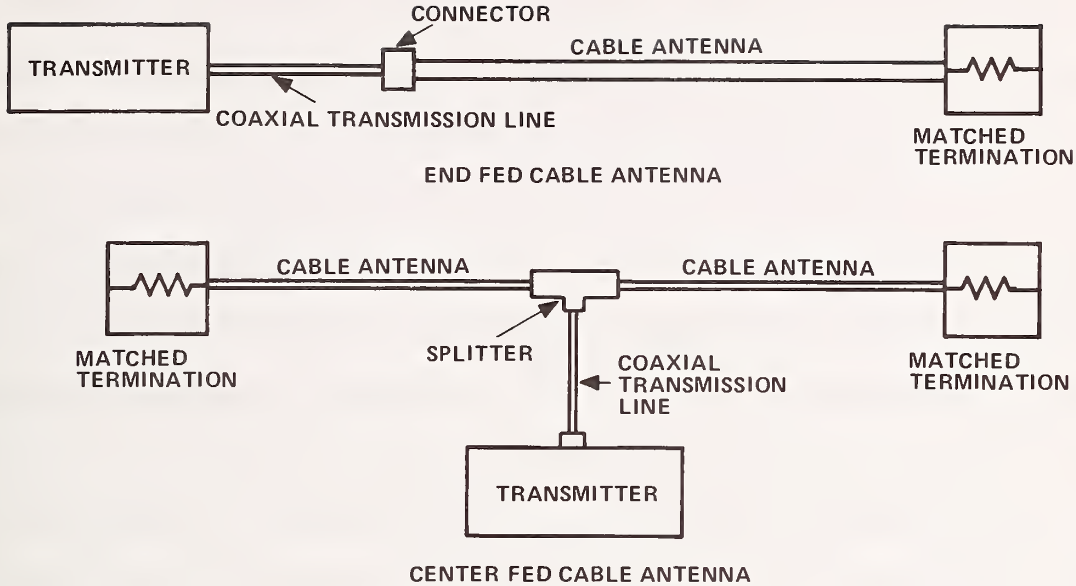


Figure 34. Cable Antenna Configurations.

Installation Options

Cable antennas are typically buried at a depth of 0.3 to 0.6 m along the shoulders of the roadways served. The right hand shoulder is preferred with respect to the direction of traffic to be addressed. On divided highways, the median strip is the other alternative. However, use of the median presents the problem of providing access for either power and telephone line drops (transmitter located on the median), or coaxial radio frequency cable (transmitter located to the side). This could require cutting a trench across the road surface or driving a conduit beneath it. It may also be possible to run lines or cable overhead using an existing structure such as a sign support that spans the roadway.

There is no requirement that cable antennas be buried. In fact, there is evidence that much stronger signals are produced if the cable is lifted above ground. This is necessary on bridges, in which cases the cable is typically secured to the guard rails, parapets or bridge superstructures. In tunnels it may be secured directly to the tunnel walls or overheads. There is no precedence for aerial suspension of cable antennas along open roadways, although technically, the concept should work very well. However, poles or any other special construction to support cable antennas would be prohibited along federal interstate highways and in many other areas as well.

Burial techniques and other practical problems of cable installation and test are discussed in more detail in Report No. FHWA-RD-80-166, "Highway Advisory Radio User's Guide."

Cable Field Strength Data

To analyze performance of cable antennas, mathematical models were developed representing both slotted cable design as represented by the Andrew Radiax, and the spiral ribbon design representative of the Halstead cable. These models are described in Report No. FHWA-RD-80-179, "Mathematical Analysis of Electromagnetic Radiators for Highway Advisory Radio," Vol. II, "Cable Antennas." The models designated AMBER and AMBER 2 (for Antenna Model of Buried Electromagnetic Radiators) are designed for use on an interactive time share basis. Input parameters for the slotted cable are:

Transmitter power (watts) and Impedance (ohms)

Characteristic impedance of cable (ohms)

Burial depth (in.), cable half length (ft.)

Radii (in.) of inner conductor and insulator

Dielectric constant of insulator

Width (in.) and orientation of radiating slots in degrees

Position of observer (X,Y,Z) in feet

Frequency (kHz)

Earth constants: dielectric constant, conductivity (mmhos/m)

Vary which parameter? (integers 1-16)

Start, stop, step

The input parameters for the spiral cable are identical except for the substitution of width (in.) and "pitch (turns per in.) of outer conductor" for statement on width and orientation of radiating slots.

To support the models, measurements were made in 1979 on three types of cable antennas along the Dulles International Airport Access Highway. The cables were Andrew RX4-3A Radiax, Halstead Comm/Scope, and Locrad NF-2. Cable lengths were approximately 1830 m. Measurements were made both prior to burial, with cables laid on top of the ground, and later after burial at a depth of about 46 cm. All cable measurements were made with approximately 10 watts RF power in. The Andrew and Locrad cable antennas were supplied new. The Halstead cable antenna was one which had previously been used on the Walt Whitman Bridge in Philadelphia, PA. Both measured data from the Dulles Highway tests and theoretical data from the model are presented in the following section on cable antenna field strength.

Field Strength Parallel to Cable Antenna at 15 m Offset

Figures 35 through 40 show the electric field strength taken along the highway at a distance of about 15 m from the buried cable. The data is taken from the continuous strip chart recordings made in a moving van equipped with a vertical monopole antenna. The fields are those which vehicles traveling along the highway would experience. The mathematical model predictions are

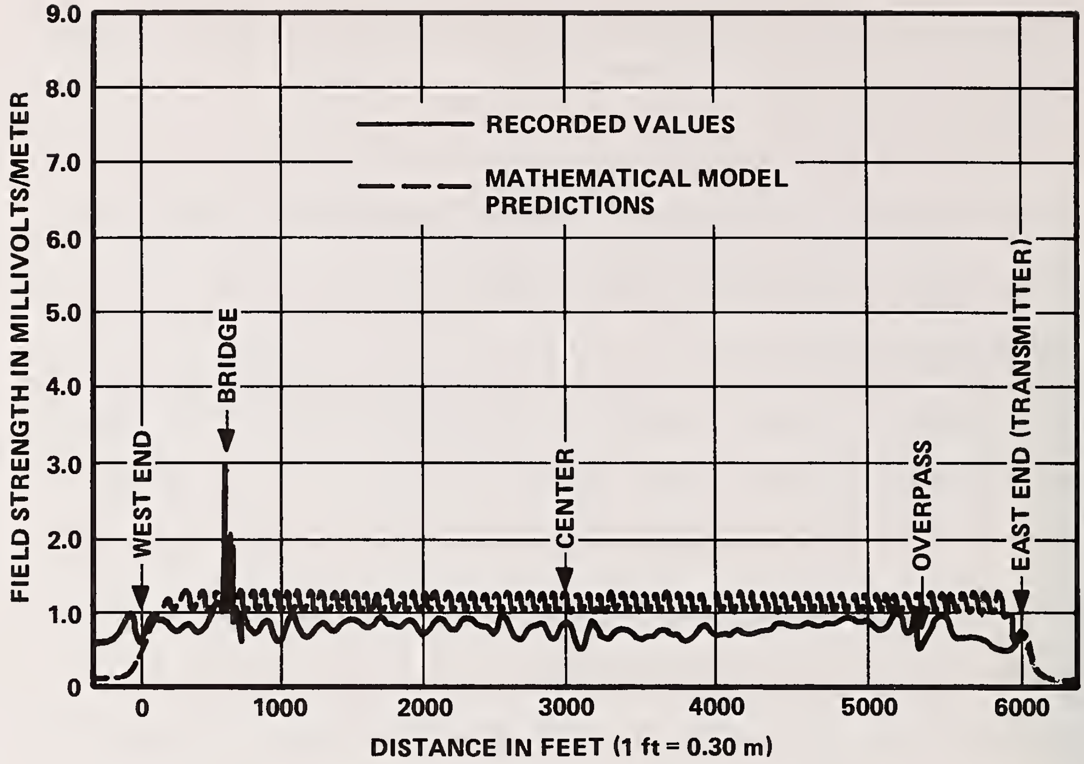


Figure 35. Vertically Polarized Electric Field, 15 m Offset, Andrew Cable Antenna at 530 kHz.

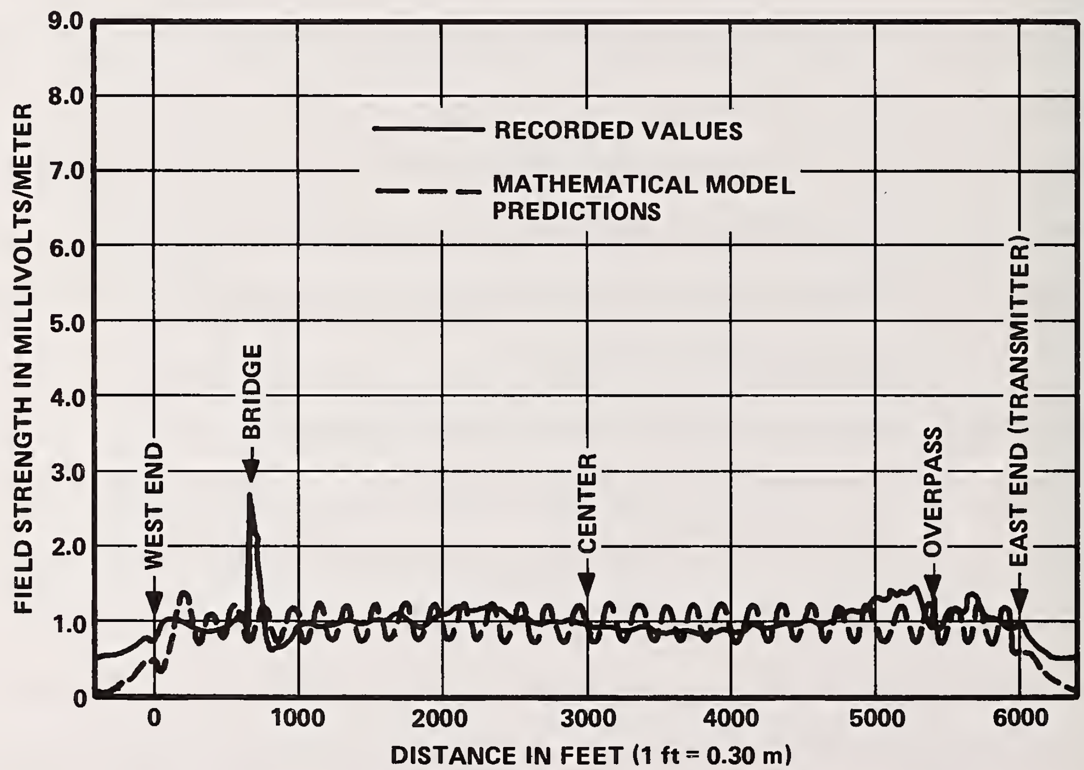


Figure 36. Vertically Polarized Electric Field, 15 m Offset, Andrew Cable Antenna at 1610 kHz.

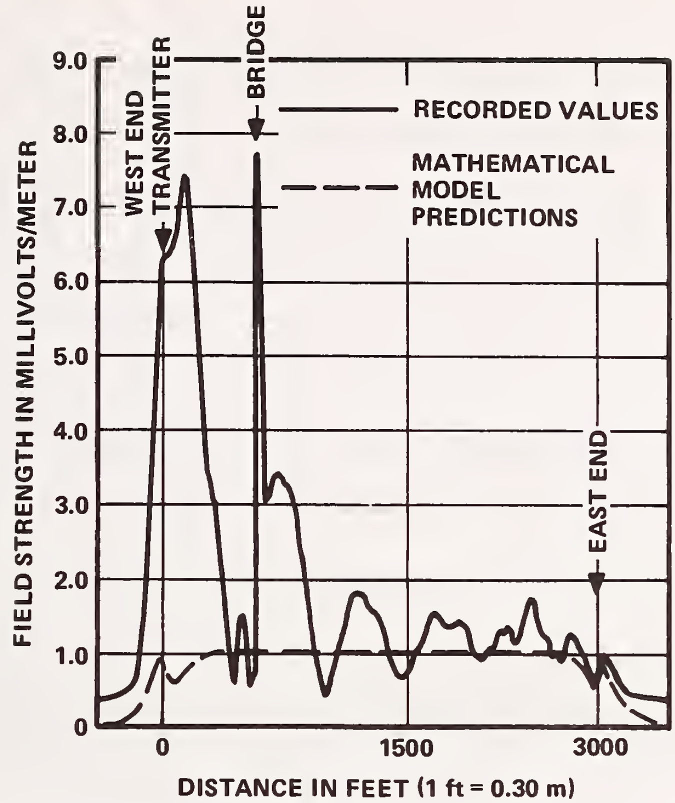


Figure 37. Vertically Polarized Electric Field, 15 m Offset, Halstead Cable Antenna at 530 kHz.

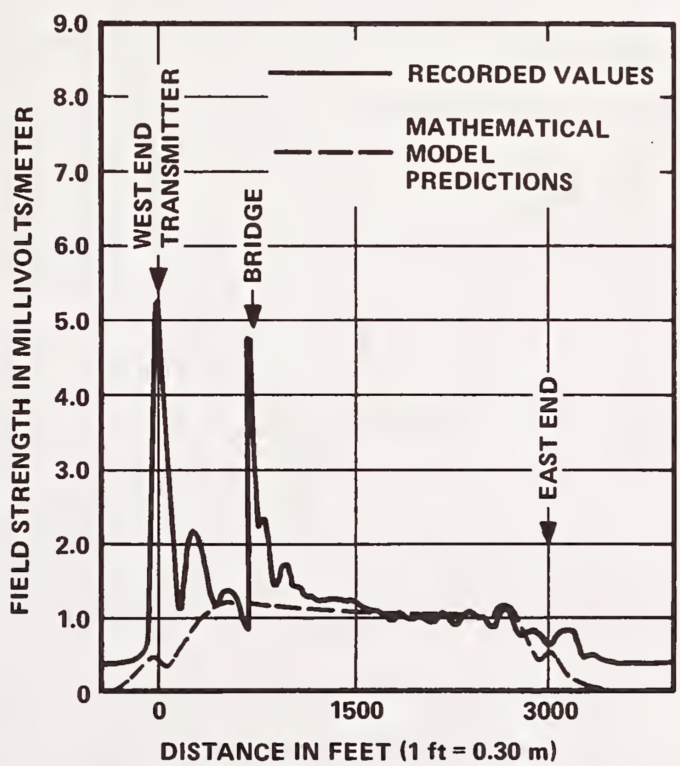


Figure 38. Vertically Polarized Electric Field, 15 m Offset, Halstead Cable Antenna at 1610 kHz.

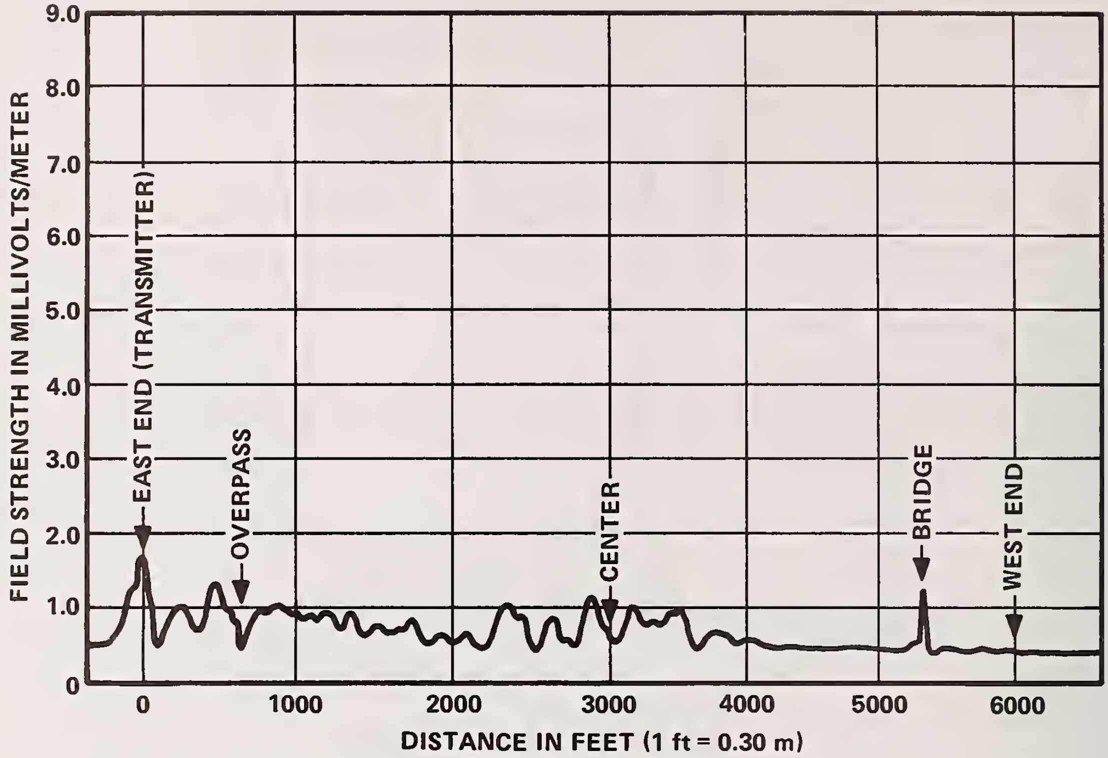


Figure 39. Vertically Polarized Electric Field, 15 m Offset, Locrad Cable Antenna at 530 kHz.

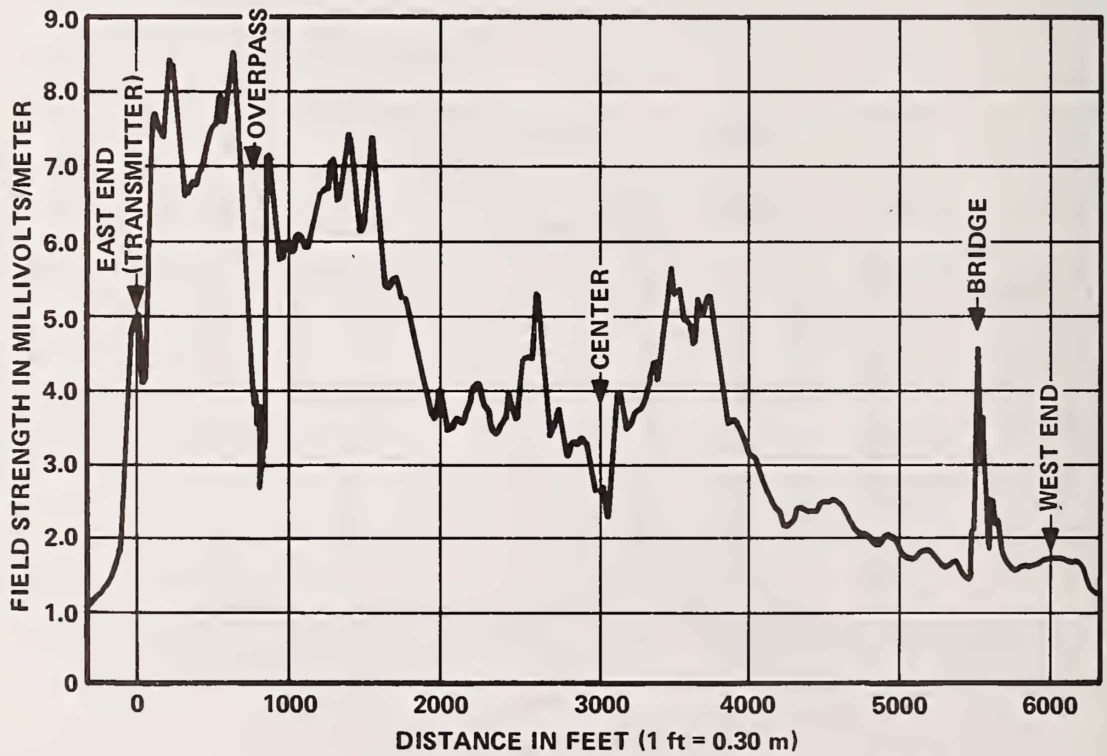


Figure 40. Vertically Polarized Electric Field, 15 m Offset, Locrad Cable Antenna at 1610 kHz.

also shown for the Andrew and Halstead cables. The model predictions assume a burial depth of 0.30 m rather than the actual depth of 0.46 m.

During the course of making measurements, it became suspected that one of the two 915 m sections of the Halstead cable antenna was discontinuous. Because of this, measurements were repeated on the 915 m section believed to be free of the problem. These are the measurements shown in Figures 37 and 38.

Field Strength Parallel to Cable Antenna at 60 m Offset

Of greater interest with respect to FCC limitations is the field strength at 60 m. This data is presented in Figures 41 through 43 for the three types of cable antennas. These measurements were made point by point with a standard field strength meter. Field strengths of the cables before burial are also shown for comparison. In making these comparisons it should be noted that the cables were fed from the center before burial and from one end after burial. As previously noted, measurements of the Halstead cable antenna are not necessarily what might have been obtained with a new cable.

Field Strength Along a Line Normal to Cable Antenna

The decrease of field strength at increasing distances from the three types of cable antennas is shown in Figures 44 through 49. The mathematical model predictions for the Andrew and Halstead cable antennas are also shown.

Of particular interest in these figures is the difference in measurements made with a loop antenna and a vertical whip. Most standard field strength meters employ a loop antenna which senses the magnetic, not the electric component of the field. Yet, such meters provide calibrated field strength in "volts per meter", which is an expression of the intensity of the electric field component. Normally, it makes no difference insofar as the two components usually have a fixed ratio with respect to each other and the value of

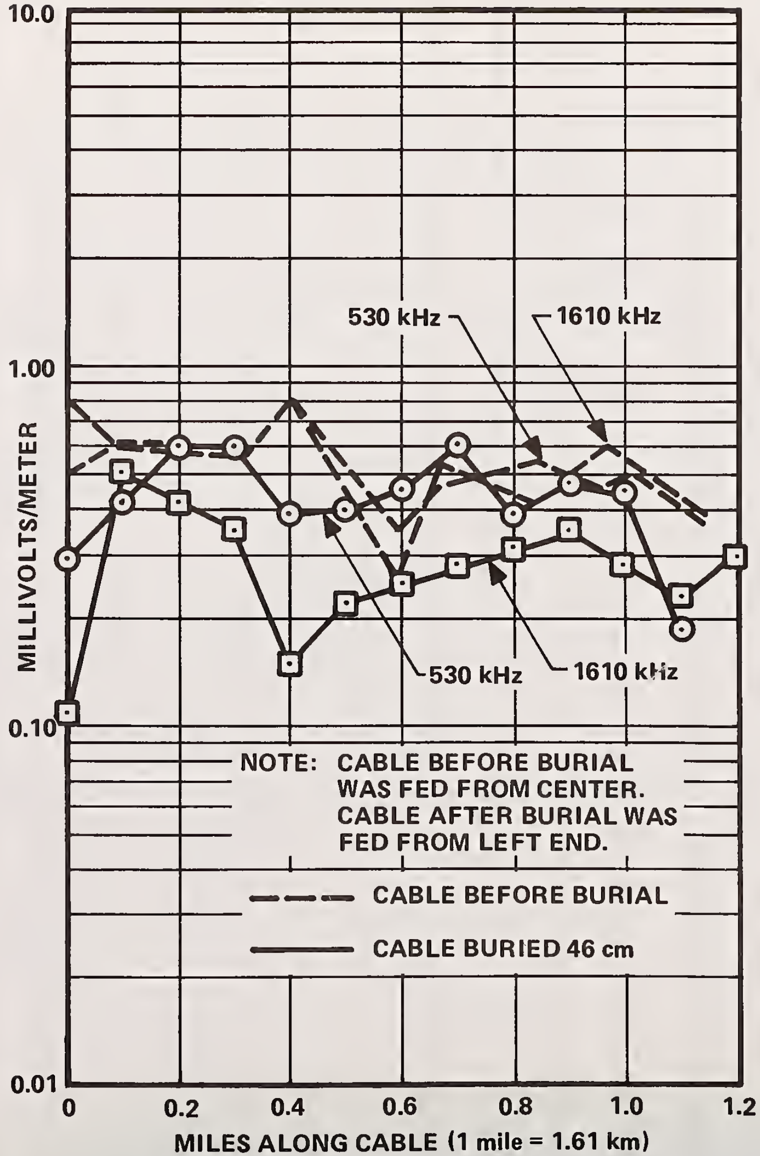


Figure 41. Andrew Cable Antenna Field Strengths at 60 Meters.

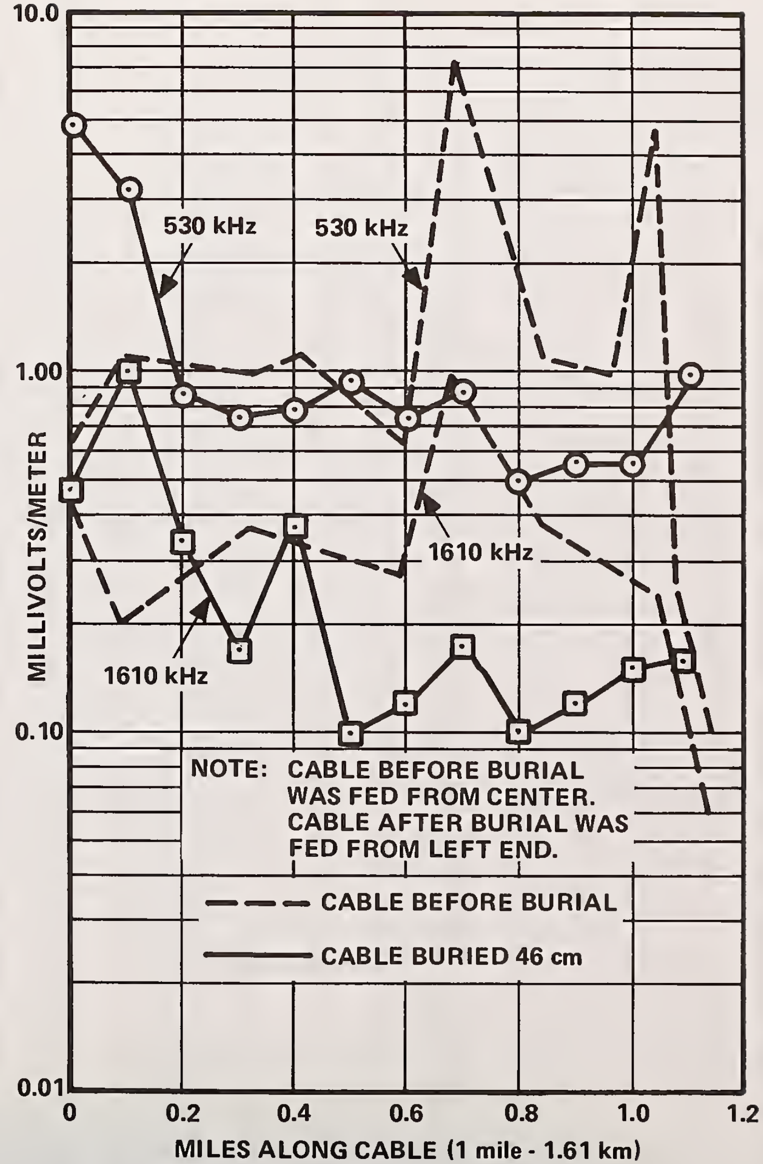


Figure 42. Halstead Cable Antenna Field Strengths at 60 Meters.

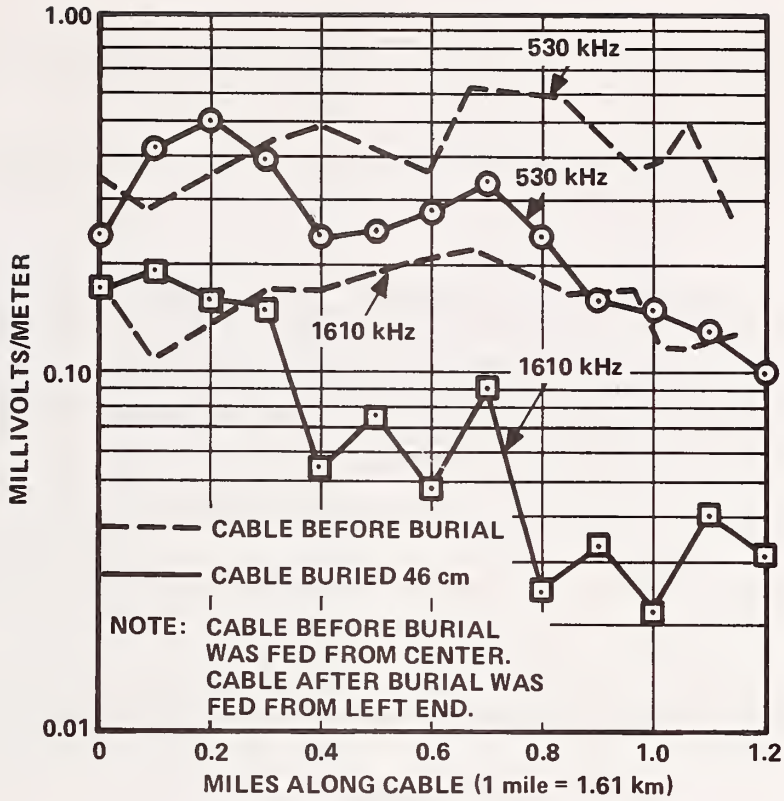


Figure 43. Locrad Cable Antenna Field Strengths at 60 Meters.

one determines the value of the other. However, in the near field of a cable antenna, this ratio requires adjustment. A standard field strength meter with a loop antenna will indicate a higher electric field strength than an instrument which directly senses the vertical electric field, as Figures 34 through 39 show. Although the differences diminish with distance they may still be discernable at 60 m and may result in a more stringent limitation on field strength than actually required by the FCC. It is therefore recommended that all cable field strength data be obtained with field strength meters calibrated for use with vertically polarized antennas. The Electro-Metrics R-70 is one field strength meter of this type. The "external input" jacks of almost any field strength meter can be used with a vertical whip provided the whip is correctly calibrated in a known field.

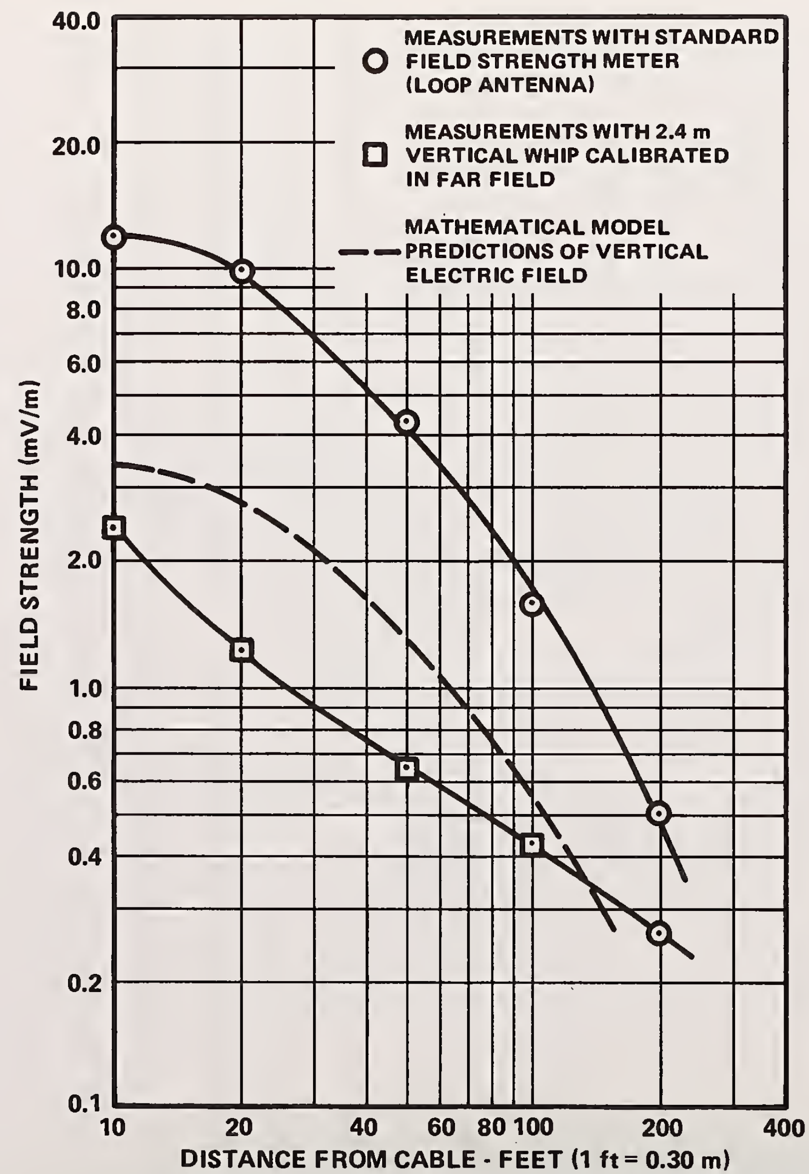


Figure 44. Field Strength Normal to Andrew Cable Antenna - 530 kHz.

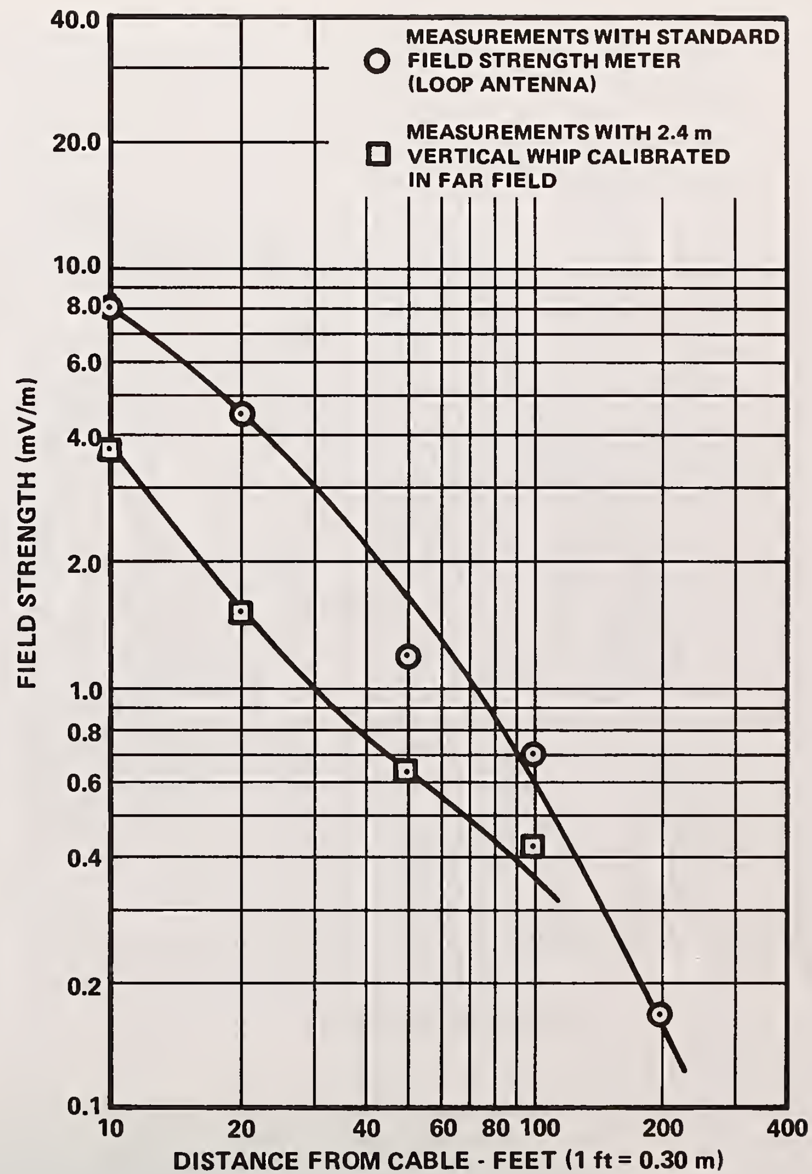


Figure 45. Field Strength Normal to Andrew Cable Antenna - 1610 kHz.

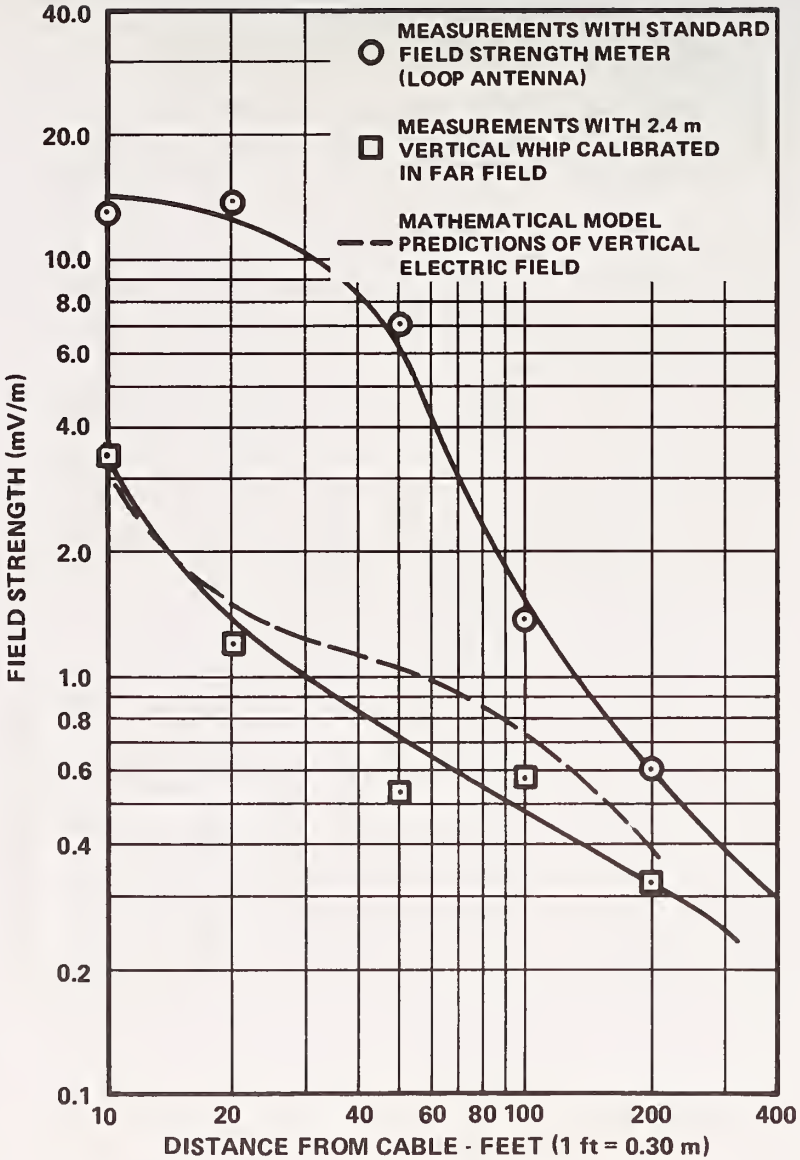


Figure 46. Field Strength Normal to Halstead Cable Antenna - 530 kHz.

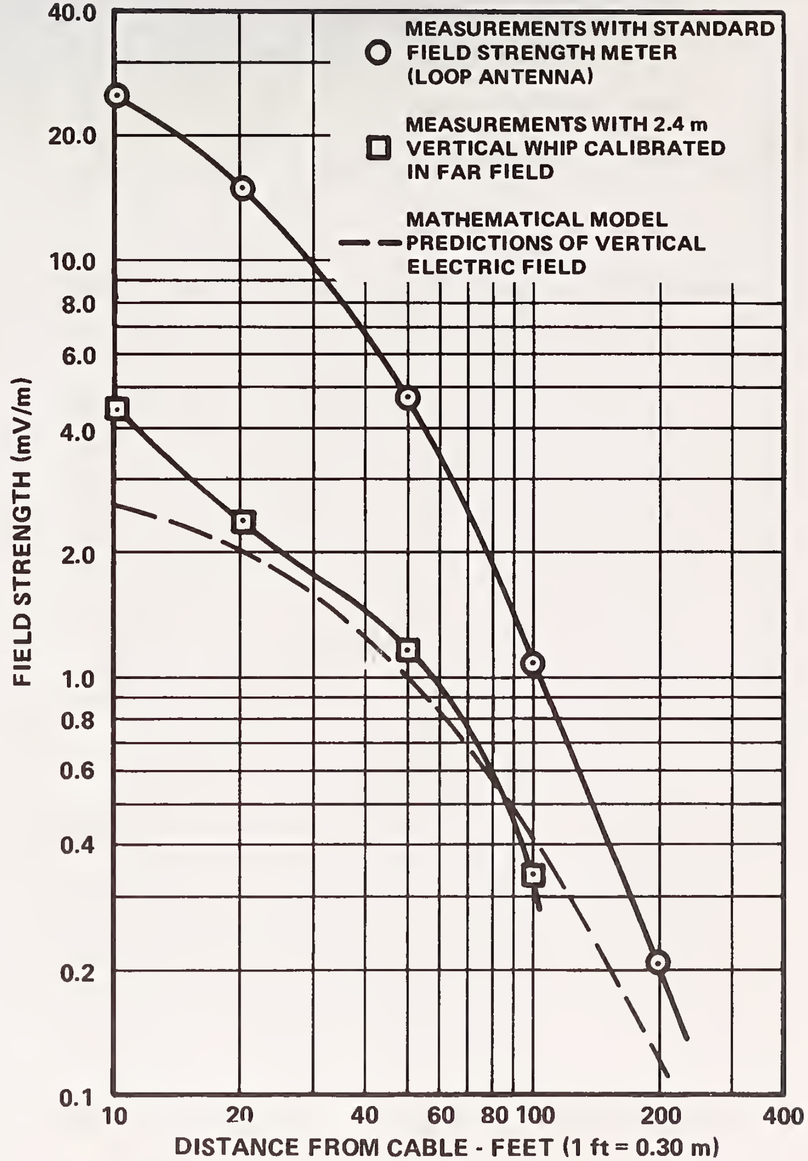


Figure 47. Field Strength Normal to Halstead Cable Antenna - 1610 kHz.

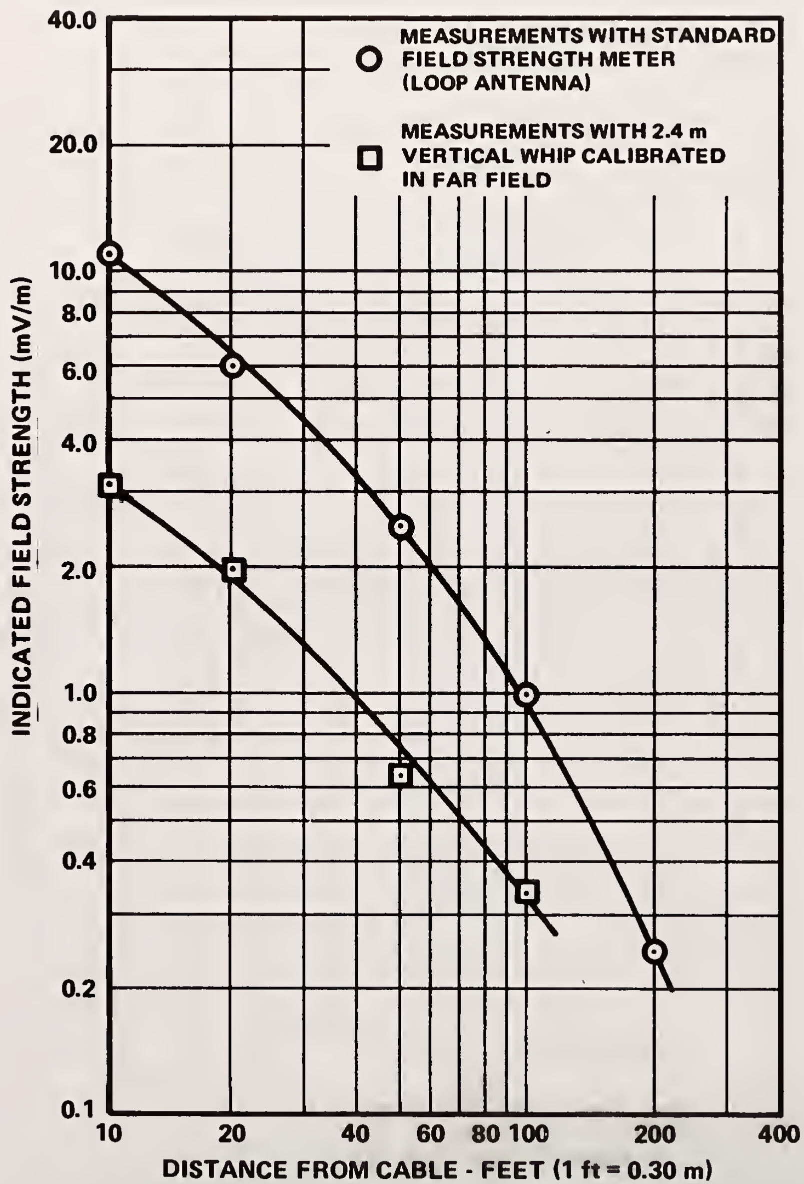


Figure 48. Field Strength Normal to Locrad Cable Antenna - 530 kHz.

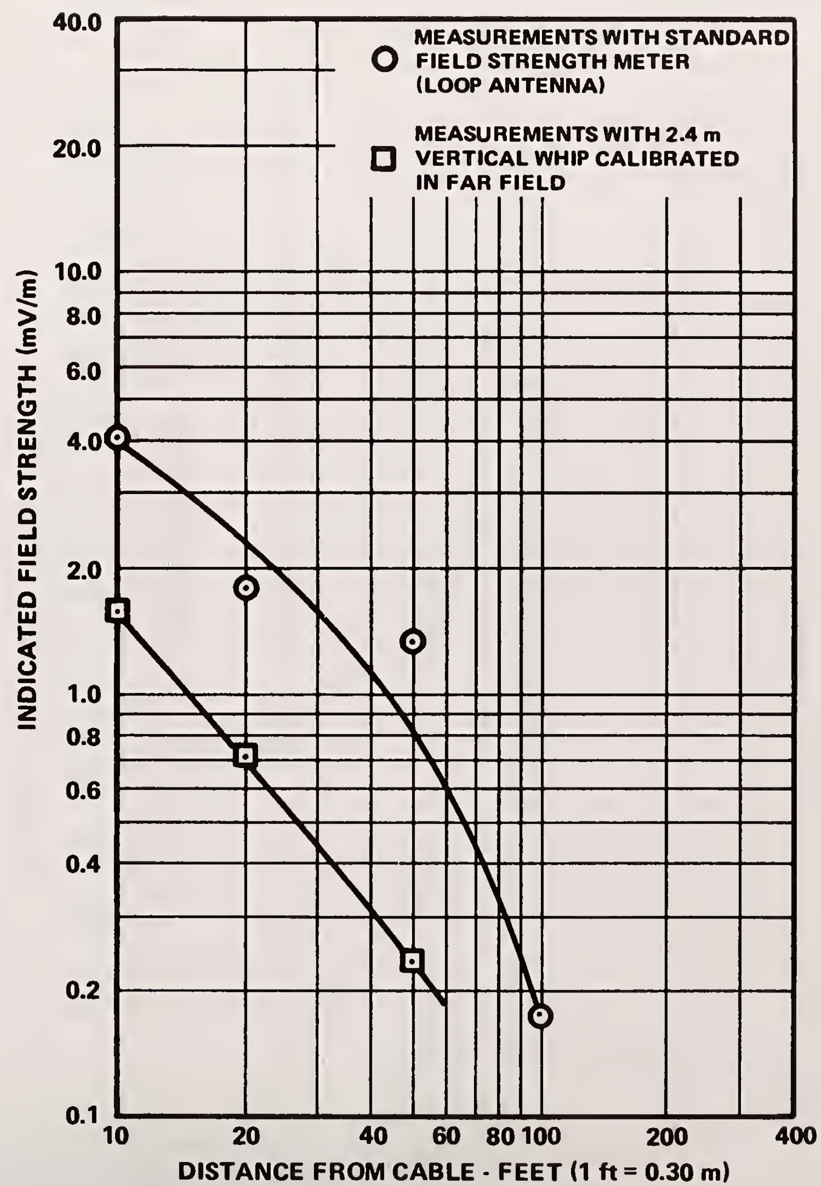


Figure 49. Field Strength Normal to Locrad Cable Antenna - 1610 kHz.

Effect of Burial on Cable Antenna Field Strength

A recommended pre-burial test procedure is to lay the cable antenna on top of the ground exactly as it is later to be installed, to connect the transmitter, and to make field strength measurements. This will give the designer confirmation that the cable is free of faults, that the expected radio coverage will be obtained, and that the FCC limit of 2 mV/m at 60 m will not be exceeded. However, some decrease in field strength can be expected upon burial. How much decrease depends on the earth constants, the depth of burial and the frequency. Observations of the three cable antenna types which were installed and tested along the Dulles International Airport Access Highway indicate that the loss is greater at 1610kHz than at 530kHz. The cable antennas measured were buried about 0.46 m in soil which at the time of the measurements was saturated with moisture. Such conditions, because of the effect moisture has on the dielectric constant and conductivity of the soil, result in lower field strength than would have occurred in comparable dry soil. Estimates of decreases in field strength as a result of burial (based on smoothing through fine variations in strip chart recordings) are:

	530kHz	1610kHz
Andrew	negligible	25%
Halstead	negligible	35%
Locrad	30%	55%

The effect of raising the cable above ground can also be seen by examination of Figures 35 through 40. The region labeled "Bridge" in each of the figures is a highway overpass where the cables were brought out of the ground and fastened to a concrete guard rail at a height of about 1.2 m above the road surface. The field strength on the overpass in all cases jumped dramatically.

The Effect of Power on Field Strength

All measured data presented in the preceeding discussion of cable antennas has been based on transmitter RF power into the cable of 10 watts. The FCC allows up to 50 watts provided the 2 mV/m at 1.5 km limit is not exceeded. Increasing power increases field strength, but only in proportion to the square root of the power increase. Figure 50 shows the appropriate field strength multipler which may be used with any of the preceeding data to determine field strengths that would have resulted from transmitter RF power outputs other than 10 watts.

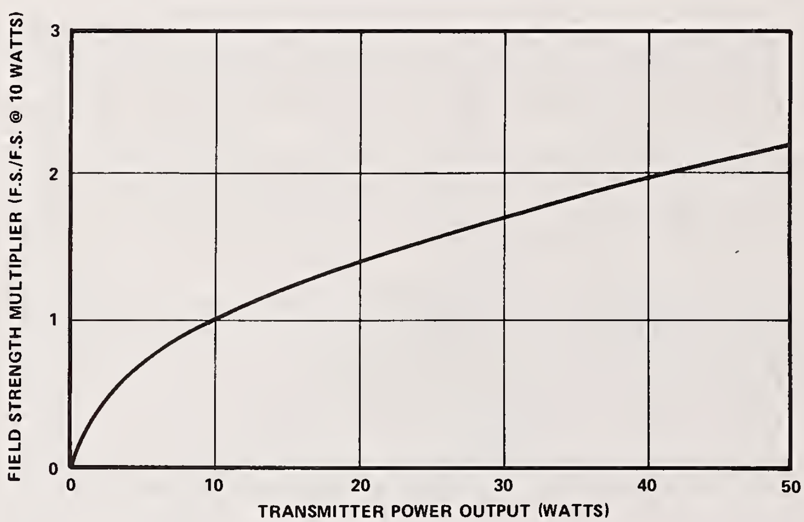


Figure 50. Relation of Field Strength to Transmitter Power.

CHAPTER 9

RECORDERS AND REPRODUCERS

Although HAR messages can be broadcast live from a microphone, the use of a recorder/reproducer as a modulation source is far more economical and practical for the continuously repeated messages most often used. Currently, there are three types of continuous loop tape formats suitable for this purpose. They are the NAB "A" size cartridges, the "Lear" 8-track cartridge, and the "Phillips" endless loop cassetts. In addition, there are the solid state memory voice storage devices which are uniquely applicable to HAR operations.

Desirable Features of HAR Recorder/Reproducers

The response of a HAR recorder or playback device need not exceed 3000 Hz. Noise suppression systems are of no value since these (such as Dolby) act to improve fidelity by suppression of high frequency noise. Stereo is not a requirement. Almost any recorder on the market will meet these conditions. What is important are those things that effect audio clarity and quality at frequencies below 3000 Hz, such as wow, flutter and distortion. Wearing qualities are exceptionally important for the tape player to be used in continuous service. The ability to operate at environmental extremes is important for recorders or reproducers to be located in outdoor cabinets. If a unit is to depend on solar panels, wind chargers or power sources other than commercial A.C. power, then power consumption could be an important factor. Table 12 is a suggested generalized specification which a recorder/reproducer chosen for HAR application should be able to meet.

Table 12. HAR Modulating Source Performance Specifications.

Modulating Source Only		Applicability
Power Requirements:	105-120 VAC, 60 Hz	All
Environmental (indoor use):	+4C min. to 50C max. (1)	All
Enviromental (outdoor cabinet):	-30C min. to 50C max. (1)	All
Frequency Response:	+/- 3dB from 300 Hz to 3,000 Hz (Ref. 1 kHz)	Tape
	+/- 3dB from 300 Hz to 2,500 Hz (Ref. 1 kHz)	Solid State
Total Harmonic Distortion:	Less than 2%	All
Wow and Flutter:	Not more than 0.2%	Tape
Output Impedance:	600 ohms nominal	All
Output Level (1 kHz):	5 dBm min. adjustable downwards	All
Tape speed:	23.8125mm per second 47.625 mm per second 95.25 mm per second	Tape
Special features:		
(1) Input and Output level indicators		All
(2) Record/playback controls		All
(3) Battery backup		Solid State

Modulating Source and Line Interface (2)		Applicability
Output Level: (3)	-10dBm min.	All
Variation of Output Level	+ or - 1 dB over 1 hour interval	All

Notes: (1) May include heating elements if required.

(2) Includes source, telephone line interface, and any line amplifiers or compressor-limiting amplifier required to meet specifications

(3) At transmitter modulation input terminals

NAB Cartridge Recorders

The NAB continuous loop cartridge has long been established in commercial broadcasting. Nearly all commercial announcements and much of the transcribed program material is now recorded on NAB type cartridges. Since the NAB cartridge has proven so reliable in radio broadcasting and because of the ready availability of the equipment on the market, a number of HAR operations are using the NAB recording systems with Type A cartridges. Type A cartridges are obtainable in a range from 20 seconds to 10.5 minutes at a standard tape speed of 190.5 mm/sec.

Nearly all NAB standard tape machines have the following characteristics:

1. Tape speed: 190.5 mm/sec
95.25 mm/sec
2. Two track heads: One for broadcast audio
One for cueing tone
3. Cueing system: 1 kHz primary tone
150 Hz secondary tone
4. Ambient operating temperature: 4 to 55 degrees C
5. Primary power: 117 VAC, 60 Hz

NAB standard tape transports are available as single deck or multi-deck units. The multi-deck transports typically combine three to six tape decks into a single cabinet with a single complement of electronics. The tape decks can be operated selectively and independently, or they may be "sequenced", such that the end of the message on one cartridge automatically transmits a cue tone which starts the next cartridge. In broadcasting, this is used to transmit a series of "spot" commercials. In HAR operations, it has been used to put together composite messages from a series of shorter, pre-recorded

statements. Thus a great variety of composite messages can be quickly constructed or altered from a library of short pre-recorded tapes.

A table of characteristics of a number of NAB standard recorder/reproducers is given in Appendix E. Because of temperature limitations, most must be used in a controlled environment, such as in a broadcast studio. At least one model, TIS Tape Deck 34-368 offered by TIS, Inc. is designed specifically for HAR use and can be operated in an outdoor, weatherproof cabinet.

Lear 8-Track Cartridge

Although widely used in cars and home entertainment systems, the "Lear" 8-track cartridge has not been utilized by commercial broadcasting stations. However, one supplier, Audio Sine, Inc. offers 8-track record and playback units which have made the use of 8-track cartridges practical in HAR operations. These units (AS-187 R/P and AS-187P) used exclusively by the U.S. Park Service, differ from most 8-track equipment in that the tape head is stationary to minimize head alignment problems, and the tape speed is one-half the standard 95.25 mm/sec to increase tape life and reduce head wear. Specifications for the Audio Sine units are given in Appendix G.

Audio-Sine generally includes 40- or 80-minute cartridges with the purchase of each AS-187. If shorter cartridges are desired, Audio-Sine, in conjunction with the tape's manufacturer, can provide this service. Audio-Sine also will provide studio quality recordings of any desired audio message at a nominal cost. It should be noted that 8-track recordings made for the AS-187 are not compatible with other 8-track equipment. The substitution of a standard 8-track tape deck would require that the cartridges be completely rerecorded.

Phillips Endless Loop Casssette

The "Phillips" cassette is the same size and dimension as the familiar tape cassette, differing only in that it employs an endless loop tape. It was originally designed for use in automatic telephone answering equipment and automatic-dialer alarm systems. It is manufactured by TDK Electronics Company and others, and is available in lengths of 30 seconds to 15 minutes. Cassette tape transports designed for commercial broadcast use are offered by Edco Products in single and multiple module combinations. Specifications for their CA-77b series are given in Appendix G. In addition, Ramko Research has recently announced their "Phase Master" which combines both cartridge and cassette modules. No cassette tape transports are currently known to be used in HAR operations, although TIS, Inc. has indicated that it plans to introduce a unit specifically for this purpose. However, the endless-loop cassette has several advantages for HAR systems over the other continuous-loop formats utilized. Some of these are listed below.

1. Ideal frequency response: 300 to 8000 Hz at 47.625 mm/sec; 300 to 4000 Hz at 23.8125 mm/sec.
2. Typical tape operating speed: 47.625 mm/sec; 23.8125 mm/sec available from some manufacturers. (Note: Slower tape speed generally implies lower playback head wear, higher tape life, and lower tape transport maintanance.)
3. Cassette transport mechanism and drive system operate identically to open reel-to-reel transport (i.e., the cassette does not have an internal pinch roller).
4. Cassette equipment generally has the lowest power consumption of all continuous-loop tape transports. (This makes cassette equipment ideal for battery-powered systems.)

5. Cassettes are the most compact continuous-loop format.

6. The endless loop cassette will operate on any commercially available cassette tape recorder. (This could prove beneficial if the primary tape deck were to fail. An inexpensive substitute could be used while the primary deck was out for repair).

Despite these advantages, one supplier of automatic voice alarm systems (Amilon Corporation, Woodside, NY) has found that the wearing properties of cassette tapes are poorer than NAB cartridges in terms of the number of passes over the record/playback head. The problem of wear can, of course, be greatly lessened by the use of the slower (23.8125 mm/sec) tape speed.

Solid State Voice Storage

The state of the art for recording and playback of continuously repeating messages is rapidly moving toward solid-state voice storage equipment. The primary benefit of this equipment is that it is not mechanical. Therefore, the problems associated with tape transport failures, tape record/playback head wear, alignment, and cleaning, as well as recording tape wear, breakage, and replacement, are eliminated. The Bell Telephone System is the prime user of voice storage units. These units are used to provide the continuously repeating recordings for wrong telephone numbers, change of telephone numbers, as well as weather, time, and other telephone information services. Other uses of the solid-state voice storage unit are: automatic telephone answering, automatic alarm systems, and automatic radio station identifiers. With sufficient recording time, voice storage units can provide a multitude of the services currently provided with continuous-loop-tape formats. They are particularly recommended when 24 hour per day operation is required.

Another unique and useful capability available in these units is the automatic time-out feature. This feature automatically disables the recording circuitry at the end of a message (indicated by a long pause) if the message is shorter than the total storage time. On playback, the unit is therefore recycled at the end of the message, not at the end of the storage period. This is a great advantage in recording since it is not necessary to assure that the message length exactly matches the storage time. (The message length may not, of course, exceed the storage time.

The cost of a solid state voice unit is determined by the storage time. A 10 second unit can be purchased for about $850 (1980). A unit capable of storing a message up to 48 seconds would cost about $2,800. This compares with $1,600 for a single deck NAB tape recorder/player.

Specificatons for three solid state voice storage recorders currently available are included in Appendix G.

CHAPTER 10

TELEPHONE LINE INTERFACING

Where the transmitter site is remote from the surveillance or control point and there is a need to make frequent and rapid changes in messages, then there is a need for some form of communications and control. One possibility is to make use of the public switched telephone network, as was done by the Iowa Department of Transportation to control HAR stations near Davenport and and Avoca from a control point in Ames. In this case, a solid state recorder can be remotely accessed by dial telephone, a new message recorded, and transmission of the new message initiated. The circuit designed to make this possible is shown in Appendix B. The system requires special decoding equipment at the transmitter site. An advantage noted by Iowa officials is the ability to program the system from any touch-tone dial telephone anywhere. The access code is restricted to authorized persons, thus barring control of the transmitter by persons not authorized by the licensee.

Private Line Interconnection Cost

Unless the user is in a position to furnish and install his own audio lines between recorder/reproducer and HAR transmitter, he will have to lease lines for this purpose from the local telephone company. Intrastate tariffs for leased private line service, applicable to the great majority of HAR systems, are on file with the public service commissions of each of the 50 states, the District of Columbia, Puerto Rico, Guam and the Virgin Islands. In addition, interstate tariffs, applicable when state lines are crossed, are

on file with the Federal Communications Commission. However, only in very unusual circumstances are HAR lines expected to extend from one state to another.

All telephone tariffs are available for inspection by the public, usually in the state capitals where they are filed. As a practical matter, they are also usually available in the local telephone company business offices. Rates will vary from state to state and even between telephone companies within a state. It will also be found that rates are given for many types and grades of lines. The standard, voice grade, unconditioned lines suitable for HAR applications in keeping with AT&T nomenclature, are often designated as Series 2000 channels. The specific type of line would have a number within this series. As an example, the C&P Telephone tariff (Virginia State Corporation Commission Tariff No. 206) list the following voice grade 2-wire lines for interconnecting customer provided equipment.

Line Type	Line Loss
2120	10 dB
2125	0-5.5 dB
2126	0-3.5 dB

The cost of these lines (1980) are as follows:

Within same building or buildings on the same premises	$1.25 per month
Different central offices (interoffice channels)	
Line charge	$1.00 per 1/4 mile per month
Terminal charge	$2.00 per month each terminal
Different exchanges (interexchange channel)	
First 25 miles	$4.50 per mile per month
Next 25 miles	$3.50 per mile per month
Each additional channel	$2.50 per mile per month
Terminal charge	$5.00 per month each terminal

These rates may be regarded as typical. However, when the potential user requires precise figures, he must consult the tariffs applicable to his specific area, and/or request rate information from his local telephone company. When ordering a private line for HAR use, the user should work closely with the telephone company customer representative to make certain that the type of line supplied is compatible with the output and input levels of the user's equipment. As an example, an Audio Sine AM-10WS transmitter requires an audio input level of about -7 dBm to produce 100% modulation. Telephone lines are usually set up with a 0 dBm 1000 Hz signal at the input terminal block (0 TPL). A line with 10 dB loss would not permit full modulation of this particular type of transmitter without the addition of an external line amplifier.

Private Line Characteristics

Leased private lines for HAR use come under the heading of non-switched point-to-point service. Although they may pass through telephone company facilities, they do not access the public switched telephone network. The user has control of both ends, which, unless the user specifies a handset or other telephone company furnished equipment, terminate in connecting blocks. Since the lines are not used for digital data, they do not require conditioning or equalization. The actual electrical characteristics may vary widely, and only certain basic parameters, such as line loss, are guaranteed by the local telephone companies. Nonetheless, some guidance can be obtained from the Bell System Transmission Engineering Technical Reference entitled "Private Line Interconnection - Voice Applications" (PUB43201). Some excerpts from this reference are as follows:

1000 Hz loss:	Specified by local telephone company
Variation in loss:	+ or -3 dB (short term)
	+ or -4 dB (long term)
Impedance:	600 ohms nominal
Frequency response:	+3 to -12 dB, 0.3 to 3 kHz (1 kHz reference)
Noise:	Down 59 dB (unweighted) from 1 kHz test tone
Test tone input level:	0 dBm (1 kHz)
Voice input level:	-13 dBm (averaged over 3 seconds)

The most critical parameter for purposes of a HAR system interface is the loss and loss variations. The line should be set up with a 0 dBm 1 kHz test tone at the input with adjustments made at the transmitter to produce 100% modulation. However, it is not uncommon for lines to be furnished with as much as 16 dB loss at set-up, with the possibility of an additional 4 dB loss occuring over a long term and 3 dB short term fluctuations superimposed on that.

In many cases, HAR operators have improved the performances of their systems by the insertion of a compressor-limiter amplifier between line and transmitter which compensates for both excessive line loss and fluctuations of that loss. Level control is provided by the compressor which decreases overall gain during high level signals and increases gain when signal levels are low. The limiter absolutely prevents peaks from exceeding a maximum. Limiter action can be switched out if desired. Compressor-limiter amplifiers are relatively inexpensive and are likely to be well worth the investment. For example, a Broadcast Electronics, Inc. Model AM 400 Compressor-Limiter Amplifier sells for $600 (1980).

Transmitter Control via Leased Lines

The same lines used for the transmission of audio can also be used to turn the transmitter on and off from a remote location. Both tone control and DC signals have been traditionally used in remote control of mobile radio systems and may be readily adapted to HAR. Touch tone pads and decoders, which are readily available and inexpensive, may also be adapted for remote control of transmitters. However, a word of caution is due to any user planning DC control. DC control requires a metallic wire pair from end to end, which few telephone companies will guarantee. Most telephone trunking, even between wire centers, is by means of multiplexed carrier circuits which will neither pass DC nor precisely preserve a tone frequency. If the line is short, and particularly if both ends terminate within the area served by a single wire center, it will very likely consist of a metallic wire pair. However, in no case should the designer plan on the use of DC control without first consulting the local telephone company.

CHAPTER 11

AUXILIARY DESIGN REQUIREMENTS FOR HAR

Siting Considerations

The location of the antenna will obviously be determined primarily by the area over which HAR coverage is desired. However, there are factors which make some locations better than others. To the extent that there is a choice, these factors should be considered. One of these is the effect of re-radiating structures. Structures that re-radiate or reflect radio energy distort the coverage pattern that one would otherwise expect from a HAR antenna. The result may be that "dead" areas occur where they were not expected or wanted. To be troublesome as re-radiators, structures generally must be:

1. Conducting or contain conductors such as steel frames, copper wiring, iron or copper plumbing, etc.
2. Greater than 1/8 wave length in height (71.3m at 530 kHz or 23.5m at 1610 kHz), or
3. Greater than 1/4 wave length in length (141.4m at 530 kHz, or 47m at 1610 kHz).

Tall buildings, water towers, radio towers, smoke stacks are examples of vertical structures that can cause problems. Power lines, bridge super-structures, guard rails and metallic fences are examples of horizontal structures that can effect field strengths. Such structures, when very near the transmitting antenna, can alter the entire coverage pattern of the antenna. Located at a substantial distance from the transmitting antenna (e.g., near the

edge of the area of coverage) the effects will be limited to the vicinity of the re-radiating structures. Structures of limited height or length, such as lamp posts, short fences or guard rails, are not generally a problem. However, they can affect antenna performance if located very close; as for example, less than 30m or so. Two recommendations are made with respect to potentially re-radiating structures. These are:

1. To the extent that a choice is available, choose the site furthest from potentially re-radiating structures.

2. If there are re-radiating structures unavoidably located near the antenna or near any area where coverage is critical, make preliminary field strength tests under an FCC "Special Temporary Authority" before applying for a permanent FCC license.

Another factor that greatly affects the efficiency of a HAR antenna is soil conditions. Good soil contributes to the efficient performance of monopole antennas. Poor soil (i.e., low soil conductivity) is preferable for cable antennas. The general soil conditions of an area are not usually a matter of choice, but something the HAR planner must accept. However, there is one aspect of soil condition that he should watch for. Fill dirt makes a notoriously poor antenna ground plane and should be avoided. If the planner has a choice of sites located in filled areas and sites on undisturbed soil, the latter are to be preferred.

Not to be overlooked is the space required for burial of the ground radials. This might be a circle of 60m or so in diameter. As discused in Chapter 5, however, perfect symmetry in the ground plane layout is not critical. For example, a "bow-tie" arrangement might prove satisfactory if a long narrow area (such as that between the highway edge and the right-of-way boundary) is

available. If a cable antenna is to be used, the number of obstacles to its burial should be reasonably small.

Electric Power Drops

Unless it is planned to use an unconventional source of power (such as a solar panel with battery storage) a power drop is essential to a HAR transmitter site. If the transmitter is to be located near a metered power source which is controlled by the licensee, or for which suitable sharing arrangements can be made, a standard 117 VAC, 15-ampere branch circuit to the transmitter enclosure will suffice. This might be practical, for example, if the transmitter is to be near a wired building, traffic control box or an electrically lighted highway sign. If branching off of a metered circuit is not practical, or if it is desired to provide separate metering, then arrangements must be made with the local power utility to provide a power drop. Typically, the utility will install (or require the customer to install) a pole with weather head, meter base, ground fault interrupter, circuit breaker and ground rods. The customer may then run an aerial or underground line from the drop pole to the transmitter enclosure. If the drop pole is not near an existing power line, it may be necessary for the utility to construct a special line to reach the drop point. The cost of such "special construction" is usually billed back to the customer as a one-time charge.

Unless the HAR license needs power for other applications, he need specify only a minimal 117 VAC 60 ampere service (the smallest permitted by National Electrical Code). Typically a HAR transmitter will draw no more than one ampere. Thus, it will consume about 2.4 kilowatt hours of electric power in a 24-hour period (i.e. usually less than 20 cents a day). All electrical installation performed for the HAR licensee should be done under the supervision of a licensed electrician and in accordance with local electrical codes.

Telephone Line Drops

When a leased telephone line is required for interconnecting the transmitter with a remotely located modulation source the exact location of the drops (i.e., the two ends of the line) must be specified. The telephone company will normally terminate each end of the line in a "split-block". Often, a fused "protection block" is inserted between the split block and the telephone companies facilities. The customer side of the split block is available to the customer to connect his own equipment.

To provide a drop at a site not inside a building (such as a HAR transmitter site) the telephone company will require a customer furnished drop pole. Usually, they will share the one provided for the electric power drop. If the drop is remote from existing telephone company facilities, a special line may have to be constructed. As in the case of power service, the cost of such special construction may be billed back to the customer as a one time charge. However, the telephone company will usually arrange to share the power company's pole line, if one is provided.

Transmitter Housing and Protection

HAR transmitters are physically small and there are electrical advantages in locating them very near their associated antennas. The result is that most are housed in weatherproof enclosures secured directly to the antenna supporting structure. Some manufacturers market HAR transmitters in their own weatherproof cases, or else sell suitable weatherproof enclosures for mounting the transmitters. An excellent housing for an unprotected transmitter is a standard traffic signal control cabinet. The larger cabinets allow room for either ventilating fans, heating elements, or both if weather extremes dictate the need for special environmental controls.

Besides the weather, there is also the need for protection against unauthorized tampering and vandalism. The FCC requires that no unauthorized person have access to the transmitter. The licensee may be even more concerned about possible equipment damage or loss. A locked transmitter enclosure is usually sufficient to satisfy both concerns. If the transmitter and antenna are located in an area where vandalism is a particular problem, the licensee may wish to consider surrounding the area with a chain link fence. However, if a fence or any metallic structure is erected near the antenna site, it may affect antenna performance. As a precaution, antenna tuning and matching should be completed after all installation is complete.

Advance Visual Signing

HAR systems requires an advance visual signing to alert motorists to the fact that an auditory message is available and where the radio zone begins. In addition, the beginning and end of the radio zone should be marked with signs. In an FHWA study, F. P. Gatling sought to determine the distance needed between the advance sign and the beginning of the radio zone. Reaction time of drivers to the advance sign and time necessary to tune to the specified frequency were measured with the radio either on or off at the time the driver saw the sign. If the radio was initially ON, 95 percent of the subjects were able to tune to the frequency in 6 seconds. If the radio was initially OFF 95 percent of the subjects were able to tuned to the frequency within 53.3 seconds.

In order to insure that drivers have enough time to see the sign and tune the radio to the proper frequency, Gatling recommended that signs be 1.6 km in advance of the beginning of the radio zone whenever possible on highways. Although the traffic congestion in urban areas may reduce the traveling speed,

this congestion also demands more of a driver's attention, thus reducing the reaction time to a sign. Therefore, the 1.6km distance is needed just as much in urban areas as on rural highways with higher traffic speeds.

Texas Transportation Institute (TTI) found that a sign message advising a motorist to tune to a particular number implied an AM radio frequency to 75 percent of drivers tested. However, to avoid possible uncertainty and a delay in the time needed to comprehend the sign, it is recommended that "AM" be included with the frequency.

In incident management and route diversion situations, drivers have been found to interpret the degree of urgency to sign message phrases as follows:

TRAFFIC ALERT	-	Greatest degree of urgency
TRAFFIC ADVISORY	-	Moderately urgent
TRAFFIC INFORMATION	-	Least urgent

The message on the advance sign should prepare the driver for the particular kind of information broadcast by the HAR station. An advance sign message should include:

A subject statement (nature of the information drivers will hear)

An action statement (tune to the designated frequency)

A location statement (distance to the signal)

The subject statement is given first. It should clearly indicate the type of radio message, i.e., traffic, travel, park, etc. The word radio should be used to clarify the action statement.

TRAFFIC INFORMATION

TUNE RADIO TO 1610 AM

1 MILE AHEAD

An example of an advance sign employed by the Iowa DOT is shown in Figure 51.

Figure 51. HAR Sign Along Interstate 80 Near Avoca, Iowa.

Operational Status of the Station

Signs should never provide false information to the motorist regarding the existence of a radio message. The motorist that finds no signal when he expects one soon ignores the sign altogether and the effectiveness of the system is destroyed. For HAR systems that operate around the clock, no special measures are required. If the system regularly operates only between certain hours, (e.g., 7AM to 7PM) this fact should be clearly indicated to the motorist. This may be done on a static sign by including the hours of operation in the visual message. If times of operation are variable, then some form of variable signing is required. Several methods that have been used

successfully to alert motorists to station status involve the use of flashing lights, signs that fold over when not in use, or interchangeable on/off indications (see Appendix H for examples).

If a HAR system is intended only for seasonal use, for example, during the summer tourist season, the signs are best removed or covered during the rest of the year.

Size, Shape and Color of Sign

The Office of Traffic Operations of the FHWA has issued recommendations for the size, shape and coloring of HAR advance signing which are consistant with the Manual on Uniform Traffic Control Devices. They are contained in Appendix H.

Information Gathering Techniques and System Application

HAR system operators monitor external conditions by a variety of methods including closed circuit television, C.B. radio reports, traffic detectors and highway work crews, and most often by state highway patrols and radio weather service reports. Some systems do not need a great deal of input; Park Service HAR systems are prime examples. The information broadcast is often quite general, including such things as park hours, rules and regulations and special seasonal attractions. Information for these systems usually does not change often, and elaborate information gathering techniques are not employed. Major construction sites utilizing HAR normally change broadcast information as road construction schedules dictate. Unless there is some abrupt change in traffic conditions such as a major accident, information will not be changed until the road conditions vary. On the other hand, systems devoted to informing the motorist of weather and traffic conditions, for instance, must have the resources available to detect changes in conditions quickly and accurately and

also the ability to convey those changes to the motorist. In the Minneapolis I-35W Urban Corridor Demonstration Project, these duties are performed by the traffic management center staff. Inputs come principally from traffic detectors and closed circuit television cameras. Traffic flow conditions are displayed on a map display panel. At the Los Angeles International Airport, information on traffic and parking conditions is provided by the airport police who normally patrol the area and monitor parking conditions. A CCTV camera on the control tower is one of the tools used for surveillance. At Houston Airport, information from parking lot status monitors, indicating when a particular lot is full, is displayed in the Airport Parking Superintendent's Office. Personnel in that office are responsible for putting on the appropriate pre-recorded tape. In the Iowa DOT system, information is supplied principally by the Highway Patrol and highway maintenance crews.

Changing Recorded Messages

The HAR system application determines the frequency and method by which the recorded messages are changed. As mentioned previously, systems used at construction sites usually have set schedules and therefore their recorded messages can be planned and made ahead of time. Elaborate remote control and remote broadcast schemes are not necessary in those instances because the application does not require immediate and dynamic updating. Park Service HAR systems are similar in that they too, usually do not need to be updated often and are also particularly well suited to having recorded libraries. Systems that provide weather and road conditions, however, require the ability to rapidly change programs. More elaborate schemes include remote controlled, multi-transport players containing different tapes describing various road and weather conditions. When conditions change, the appropriate transport is

actuated by remote control and the selected program is broadcast. One scheme, used by the Iowa DOT and previously described, includes the capability to change the message broadcast by remotely re-recording a tape in the player at the transmitter site. Remote control is accomplished through the use of touch tone telephone pads and tone decoders.

In instances where remote control is not available or needed, the most conventional method of changing programs is to simply re-record the tape and re-insert it in the player. Other options include maintaining libraries of most often used tapes and changing the tape in the player to the one describing the appropriate conditions. It is usual to also maintain scripts of those tapes, or any tapes for that matter, for use in re-recording should the tape become excessively worn or otherwise damaged. New tapes can then be prepared as circumstances dictate and added to the library. Although some tape transports provide for recording, separate tape recorders are usually used to record tapes. Professional recording studios may also be utilized, although the delay and expense involved may preclude this.

Message Length

With audio messages, it is important that the driver hear the message at least twice for maximum recall. In order to distinguish the beginning and end of the message there must be a pause or signal. Many drivers will enter the radio zone after the beginning of the message. In order for these drivers to hear the message twice, there should be sufficient time to repeat one-half of the message in addition to the two full repetitions.

Based on a coverage zone of about 3 km, which the maximum length of cable would permit, the following maximum message would apply.

Operating Speed (km/hr)	Maximum Exposure Time (min)	Recommended Maximum Message Length (secs)
90	2.0	45
75	2.4	55
60	3.0	65
45	4.0	90
30	6.0	135

CHAPTER 12

COSTS

Initial Design and Installation

The initial or capital cost of an HAR installation quite obviously depends upon the complexity of the system. Some typical costs of various configurations are given in Tables 13 through 16 corresponding to the configurations decribed in Chapter 4 and shown in Figures 6, 8, 9 and 10. These are respectively a basic HAR system, a system with remote console and modulating source, a system with "dial-up" control of a solid state voice storage modulating source, and a three-station wide area coverage system. All estimates are given assuming commercial monopole antennas. The costs of systems utilizing cable antennas would differ only to the extent that antenna costs differ. Cable costs vary from \$3,300 to \$6,600 per kilometer with another \$1,000 per kilometer estimated for burial along a relatively unobstructed earthen shoulder (1979 prices).

Operating Cost (Exclusive of Operating Personnel)

Operating costs will include telephone line rental, electric power, and maintenance. Telephone line rental is obviously dependent on line length. For a local channel within a central office area, a typical charge is a flat \$5.00 per month, or \$60 per year. Electric power for a transmitter and tape player operating 24 hours a day (0.3 KW x 24 hours x 365 days x \$.05 per KWH) would be about \$130 a year. Maintenance, assuming a maintenance technician makes 6 service calls a year at \$100 per call, may run \$600 per year. If the

Table 13. Estimated Installation Costs, Basic HAR System (Reference: Chapter 4, Figure 6).

Materials	Cost
Cartridge Tapes, 10	$ 50
Creosote Pole, Erected on Site	400
Ground Rods, 16	240
Lot, Ground Wire	80
Lot, Misc. Cable, Hardware	500
Antenna with Matching Coil	250
Single Deck Cartridge Tape Machine	1,575
Ten-Watt HAR Transmitter, with Power Supply	1,400
Transmitter Housing, with Padlock	820
Total Materials	$ 5,315
Planning and Design	$ 4,000
License Application	$ 1,000
Installation	$ 5,000
Performance Testing	$ 2,500
Signing (materials and installation)	$ 5,000
TOTAL INVESTMENT	$22,815

Table 14. Estimated Installation Costs, HAR System With a Remote Console and Modulating Source (Reference: Chapter 4, Figure 8).

Materials	Cost
Audio Compressor/Limiter	$ 625
Cartridge Tapes, 10	50
Creosote Pole, Erected on Site	400
Ground Rods, 16	240
Lot, Ground Wire	80
Lot, Misc. Cable, Hardware	500
Antenna with Matching Coil	250
Single Deck Cartridge Tape Machine	1,575
Single Deck Tape Player	825
Ten-Watt TIS Transmitter, with Power Supply	1,400
Transmitter Housing, with Padlock	820
Recording Console with Monitor Amplifier, Speaker and Microphone	2,500
Total Materials	$ 9,265
Planning and Design	5,500
License Application	1,000
Installation	8,500
Performance Testing	5,000
Signing (materials and installation)	5,000
TOTAL INVESTMENT	$34,265

Table 15. Estimated Installation Cost HAR System With Remote "Dial-Up" Control of a Solid State Voice Storage Modulating Source (Reference: Chapter 4, Figure 9).

Materials		Cost
Creosote Pole, Erected on Site		$ 400
Ground Rods, 16		240
Lot, Ground Wire		80
Lot, Misc. Cable, Hardware		500
Antenna with Matching Coil		250
Ten-Watt HAR Transmitter, with Power Supply		1,400
Transmitter Housing, with Padlock		820
Solid State Voice Storage Unit		2,000
Ring Detector and Decoder Circuits		2,000
	Total Materials	$ 7,690
Planning and Design		5,000
License Application		1,000
Installation		7,500
Performance Testing		4,000
Signing (materials and installation)		5,000
	TOTAL INVESTMENT	$30,190

Table 16. Estimated Installation Cost
Three Station Wide Area Coverage HAR System
(Reference: Chapter 4, Figure 10).

Materials	Cost
Audio Compressor/Limiter (3)	$ 1,875
Cartridge Tapes, 20	100
Creosote Pole, Erected on Site (3)	1,200
Ground Rods, 48	720
Lot, Ground Wire	240
Lot, Misc. Cable, Hardware	1,500
Antenna with Matching Coil (3)	750
Single Deck Cartridge Tape Machine	1,575
Single Deck Cartridge Tape Player	825
Ultra-Stable Ten-Watt HAR Transmitter with Power Supply (3)	7,200
Transmitter Housing with Padlock (3)	2,460
Recording Console with Monitor	3,500
Amplifier, Speaker, and Microphone Line Amps (3)	240
Total Materials	$22,185
Planning and Design	8,500
License Application	2,000
Installation	16,000
Performance Testing	11,000
Signing (materials and installation)	15,000
TOTAL INVESTMENT	$74,685

user must use personnel outside the user organization for maintenance, he may choose to sign a service contract in which a maintenance organization undertakes to maintain the equipment at a fixed annual rate (convenient for budgetary purposes) or he may choose to pay only for services rendered whenever such services are required. It is very important to include in a service contract a maximum response time after notification of a problem, and whether service will be limited to business hours only, or will be available 24 hours a day, 7 days a week. As may be expected, most service organizations require a substantial premium for 24 hour, 7 day service.

Operating Personnel Cost

Not to be overlooked is the cost of personnel who perform the surveillance, record the messages and monitor the operation of the system. This can vary over a very wide range between systems that provide information that is not urgent and changes infrequently, and systems providing urgent but rapidly changing information. The former might require the part-time attention of an individual normally assigned to other duties, the latter might require a full time staff. The user should be certain that the necessary staff will be available and that responsibilities are well understood. Costs will depend on the number of persons involved and the percentage of their time required. In calculating such costs, the user will wish to take into account any cost savings that the system will bring about. For example, if police personnel are utilized to provide surveillance information in a HAR system designed to reduce traffic congestion, would the reduction in congestion require fewer police on the scene directing traffic? This would be a direct saving against the operating budget. Indirect savings might also occur in time and energy savings to the motorists no longer having to contend with traffic delays.

CHAPTER 13

DESIGN EXAMPLE

In this chapter the considerations that influenced the actual design of a HAR system in Gatlinburg, Tennessee are discussed. Planning for the system began in 1978 and experimented propagation measurements were made under an FCC granted Special Temporary Authorization (STA) in December of that year. FCC applications for permanent authorizations were filed in Februrary, 1979.

All applications were granted and stations were installed and operating at three of four planned sites by early 1980. Negotiations for land use have caused delay at the fourth site. An objective was to have the system in full use by the beginning of the 1980 summer tourist season.

Need and Justifications for HAR

Gatlinburg is situated at one of the entrances to the Great Smoky Mountain National Park. Although it has a permanent resident population of only 2,800, it acts as host to an estimated 3 million of the 9 million visitors to the Park each year. On any one day during the tourist season, Gatlinburg may accommodate more than 30 thousand visitors. Traffic jams are common.

The request for HAR by the City of Gatlinburg was based on the need for traffic control and the dissemination of tourist information. Also cited in its applications to the FCC was the need for a public safety warning system. The Tennessee Valley Authority has assessed Gatlinburg as more prone to

flooding than Johnstown, PA. In the event of such flooding, HAR announcements would be used to divert motorists away from the area.

Design Configuration

It was desired to provide a common message to motorists on route to Gatlinburg along all the major approaches. The choice was therefore to use four transmitting sites each equipped with omnidirectional monopole antennas, which together, provide the coverage needed. Locations with respect to the city are shown in Figure 52. One site covers the town of Gatlinburg. A second site covers the approach to city along US 441. A third site covers the State Route 73 approach. The fourth site is on I 40 at the State Route 66 intersection where a great deal of traffic normally leaves I 40 for Gatlinburg. The present plan is to modulate all stations simultaneously from the same audio source to be located in downtown Gatlinburg. Interconnection between the source and the transmitting stations is to be supplied by standard telephone lines furnished by the local telephone company. A block diagram of the system configuration is shown in Figure 53.

Site Locations

The four sites chosen are as follows:

1. Downtown Site - 76 m southwest from intersection of US 441 and Tennessee State Route 73. Neither is a Federal Interstate Highway. However, the site is located approximately 120 m from the Trailways Bus Terminal and approximately 180 m from the Ogle Home, a registered State Historical Site.

2. Golf Course Site - 430 m northeast of US 441 on the city owned Gatlinburg Golf Course. The area is identified by the state as a recreational area. Further, it is in the vicinity of an operating water mill built in 1830 and now recognized as an historic site by the National Historic Registration.

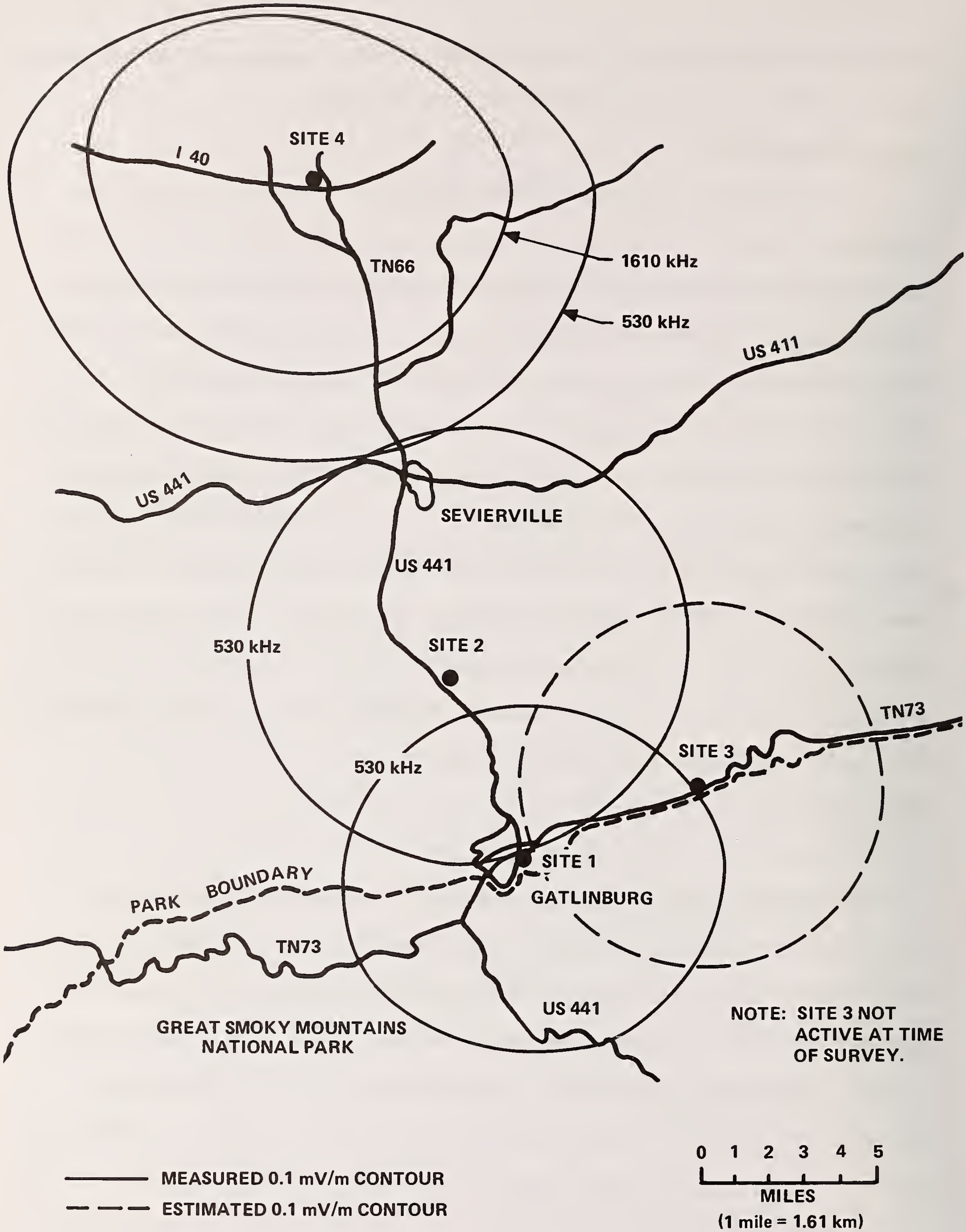


Figure 52. Gatlinburg HAR Sites.

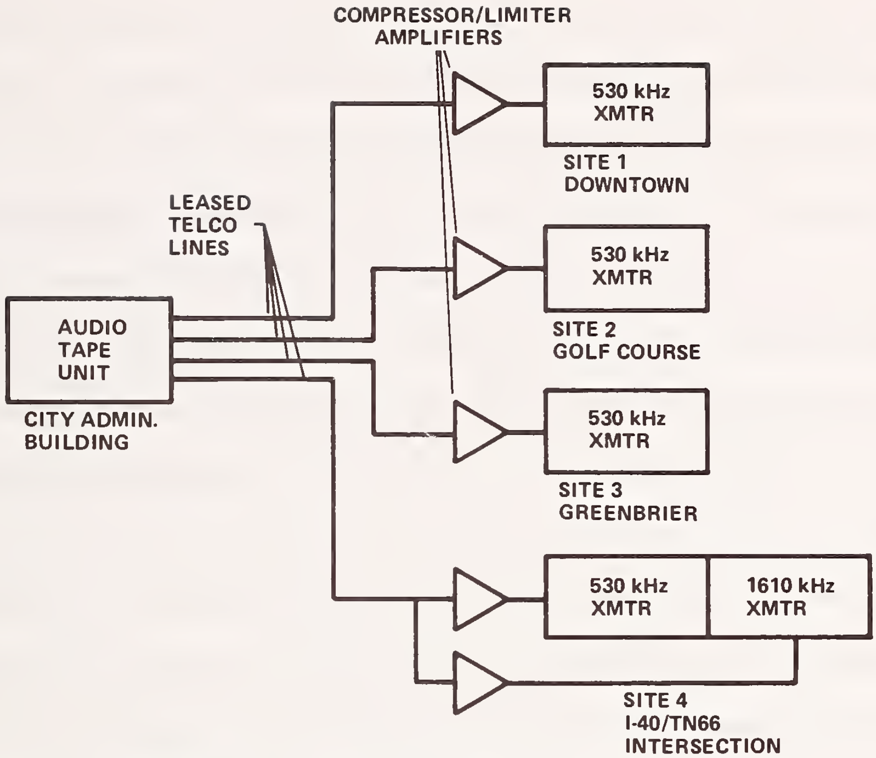


Figure 53. Gatlinburg System Configuration.

3. Greenbrier Site - 46 m northwest from State Route 73 and 61 m west from the bridge crossing the Little Pigeon River. It is also opposite the National Park Service road to the historic Greenbrier Ranger Station, 1.37 km southeast. The Greenbrier Ranger Station is maintained today only as a tourist attraction to show what one of the early ranger stations looked like.

4. I-40/Rt. 66 Intersection - 91 m northwest of the west going on-ramp to Federal Interstate 40 leading from State Route 66 headed south. The site is located on a Texaco service station property.

Frequencies

Sites 1, 2 and 3 are barred from the use of 1610 kHz because of the proximity of National Park Service HAR stations on that frequency in the Great Smokey Mountain National Park. All four sites were found eligible for the use of 530 kHz. The nearest adjacent channel stations (540 kHz) were found to be

WRIC in Richlands, VA and WDXN in Clarksville, TN. All four HAR sites are more than the required 15 km beyond the 0.5 mV/m contours of these two stations. The nearest second adjacent channel station (550 kHz) was noted to be WGGA in Gainesville, GA, more than 161 km (100 miles) from any of the four sites. Even more remote is the nearest third adjacent channel station (510 kHz), which was noted to be WIS, Columbia, SC, a distance of 304 km from the nearest of the four HAR sites. Except for the four sites proposed, there were found to be no other HAR operations on 530 kHz in operation or pending in the vicinity.

Site 4 was also found to be eligible for 1610 kHz. The nearest co-channel station is operated by the National Park Service at a distance of 34 km. The nearest broadcast stations on the adjacent channel (1600 kHz) were found to be WHBT in Harriman, TN, WHVL in Hendersonville, NC and WEUP in Huntsville, AL. Site 4 is well outside the 0.5 mV/m contour of all three stations, including that which would result from a proposed increase in power of WHVL. There are two stations within 161 km on 1590 kHz. These are WBHN, Bryan City, VA at 63 km, and WJSO, Jonesboro, NC at 121 km. WBHN operates daytime only with 500 watts into an omnidirectional antenna. Site 4 is outside the 25 mV/m contour of both stations (see Chapter 2). The only third adjacent channel (1580 kHz) of consequence is WKST in Knoxville, TX. This station is at a distance of only 27 km from site 4. WKST operates with 5 KW into a non-directional antenna and is computed to produce a field of less than 1 mV/m at site 4. This meets the requirement that the HAR station be outside the 25 mV/m contour of a third adjacent channel station (see Chapter 2). No interference is therefore expected.

Five applications for FCC authorization were filed in February 1979. Four were for a 530 kHz station at each of the four sites. The fifth was for a 1610 kHz station at site 4 only. All applications were granted.

Antenna Design and Installation

Prior to the submission of FCC applications, tests were made on 530 kHz at each of the proposed sites under a Special Temporary Authority (STA) granted by the FCC. The antenna used was a commercially available Morad SF 530A which was temporarily clamped to a short wooden stake for tests at each site. Six 30 m radials were stretched out on top of the ground (or the surface of the parking lot at a downtown site). Smoothed* values of field strength at 1.5 km varied from 0.4 to 0.7 mV/m. This was less than desired and less than the 2 mV/m at 1.5 kilometers permitted by the FCC. To increase coverage, it was decided to elevate the Morad SF 530A to the maximum permissible height by permissible height by mounting it at the top of a wooden utility pole having a height of about 9.5 m above the ground level. The installation is illustrated in Figure 54. In addition, the number of 30 m ground radials was increased to 16. Except at the downtown site, the radials were buried about 150 mm inches below the surface of the ground. The radials were silver soldered together at the base of the antenna structure. The outer ends were silver soldered to 0.5 m spikes which were driven into the earth. The radials at the downtown site were laid into slots cut with a diamond saw into the asphalt composition surface of the parking lot. The slots were subsequently filled with molten asphalt.

*Taken from a curve drawn through a number of points taken at varying distances.

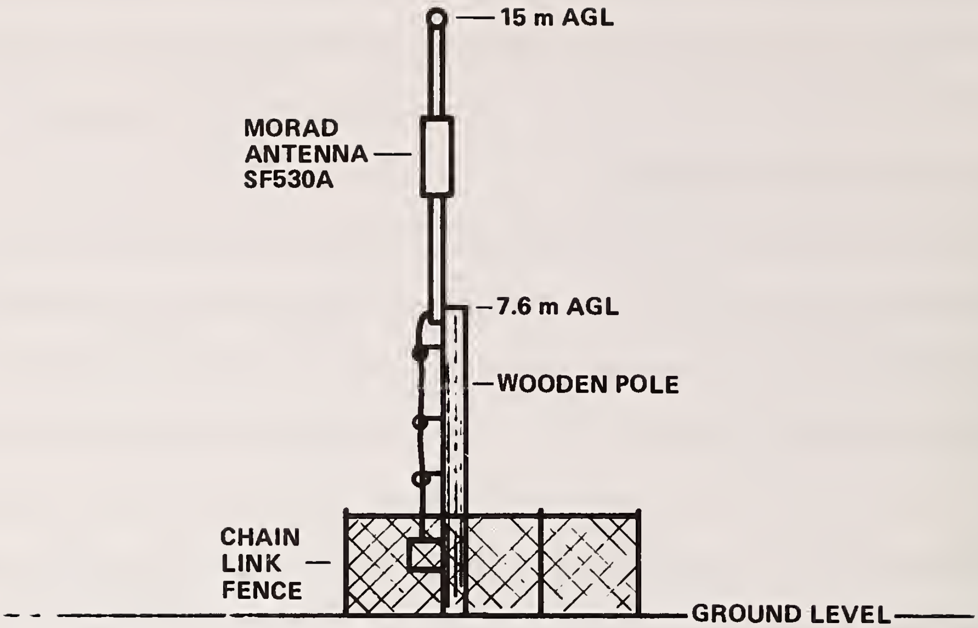


Figure 54. Antenna Plan, Gatlinburg HAR Sites.

Measurements on the completed antenna systems gave smoothed values of field strength varying from 1.2 to 1.9 mV/m at 1.5 km. This represents a six-fold increase in efficiency. No actual measurements at 1.5 km exceeded the FCC limit of 2 mV/m.

Transmitters

The choice of transmitters was predicated upon the need to avoid inter-modulation interference between adjacent sites. As may be observed in Figure 52, the measured 0.1 mV/m contours show considerable overlap. Site 3, not yet active at the time of the measurements will itself overlap Site 1 and 2. A signal strength of 0.1 mV/m is more than enough to cause co-channel interference unless the transmitter frequencies are very nearly the same. Although commercially available transmitters are required to meet type acceptance criteria which limits carrier frequency drift to plus or minus 100 Hz within

specified temperature and supply voltage limits, this is not enough to prevent audible heterodynes in a receiver within range of two or more transmitters. The solution was to modify a commercially available 10 watt transmitter, the Audio Sine AM 10 WS, by the addition of a Vetron CO-214 high stability oven controlled frequency source. The composite unit is diagrammed in Figure 55. Additional type acceptance tests were required and performed. Type acceptance was granted under the composite identification JB-1C. Frequency drift was shown to be less than plus or minus 1 Hz. This permits two or more units to operate in close proximity with no audible affects except possibly along the contours of equal field strengths, where theory shows that a slow fading in and out might be observable.

Audio Recorder

The City has two Audio Sine recorder/players and an automatically reversible two-track open-reel recorder/player. The latter (a donation to the City) will playback one track and, upon reaching the end of the tape will reverse itself and playback the second track in the opposite direction. At the end of the second track, it will again playback track one. This procedure continues to be repeated indefinitely. The present plan is to use the open reel machine and to reserve the two Audio Sine recorders as back-ups.

Leased Line Interfaces

Interconnection between the audio tape unit in the City Administration Building and the HAR transmitter sites is by standard voice grade telephone lines furnished by the local telephone company. Compressor/limiter amplifiers are used between line and transmitter audio input to: (1) compensate for variations in line level, and (2) to process the audio to produce positive peaks 25% higher than negative peaks. This technique has been used by AM

broadcasters to increase modulation (and signal-to-noise ratio at the receiver output) without over modulating and causing distortion on the negative peaks.

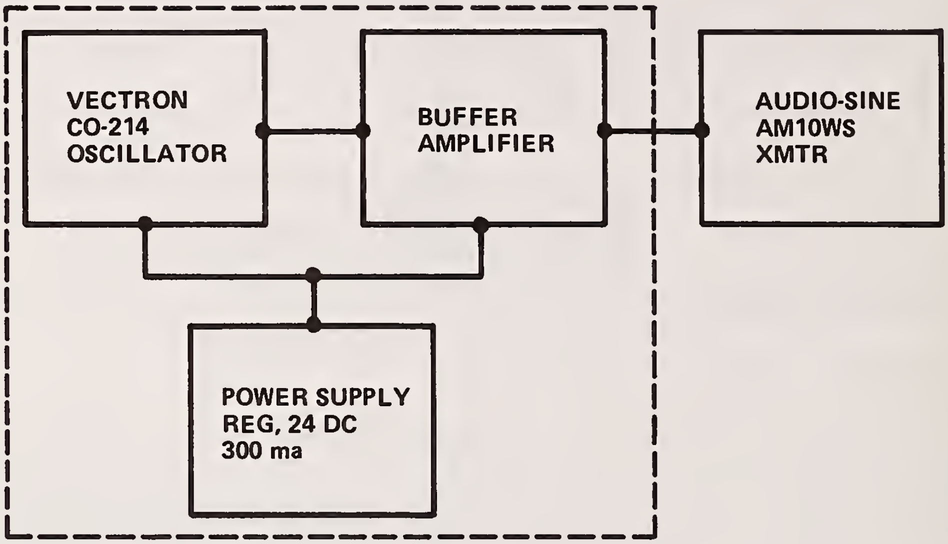


Figure 55. Composite High Stability Transmitter.

BIBLIOGRAPHY

Anderson, R.A., and Robertson, R.G., "A Study and Development of Highway Advisory Information Radio", Report No. FHWA-RD-74-73, Atlantic Research Corporation, December 1974 (NTIS PB 240246/AS).

Carlson, G.C. et al., "Evaluation of Highway Advisory Radio in the I-35W Traffic Management Network," Report No. FHWA-RD-79-33, Minnesota Department of Transportation, March 1979 (NTIS PB 297144/AS).

Dorsey, W.F., "Highway Advisory Radio Operational Site Survey and Broadcast Equipment Guide," Report No. FHWA-RD-79-87, Federal Highway Administration, April 1979.

Dorsey, W.F. and Pattakos, D., "1610-kHz Automobile AM Radio Reception," Report prepared for the Federal Highway Administration, Traffic System Division, System Development and Technology Group, October 1979.

Dudek, C.L. et al., "Human Factors Requirements for Real Time Motorist Systems," Texas Transportation Institute, Texas A&M University, 1977.

Gatling, F.P., "Auditory Material for Route Diversion," Report No. FHWA-RD-75-73, Federal Highway Administration, June 1975.

Gatling, F.P., "Highway Advisory Radio in Construction Areas," Report No. FHWA-RD-77-168, Federal Highway Administration, December 1977.

Gatling, F.P., "Further Studies on Auditory Messages," Report No. FHWA-RD-77-130, Federal Highway Administration, October 1977.

Gatling, F.P., "The Effect of Auditory and Visual Presentation, Navigational Messages on Message Retention," Report No. FHWA-RD-76-94, Federal Highway Administration, 1976.

McFadden, R.R. and Shoaf, J.H., "Travelers Information Station Planning Handbook," National Park Service, Denver Service Center, Denver, Colorado, December 1978.

Federal Communications Commission Rules and Regulations
Part 2, Frequency Allocations and Radio Treaty Matters; General Rules and Regulations (Subpart J contains rules pertaining to transmitter type acceptance).
Part 73, Radio Braodcast Service (Subpart A contains field strength information applicable to HAR).
Part 90, Private Land Mobile Radio Services (contains rules applicable to HAR stations).

National Association of Broadcasters Engineering Handbook, 6th Edition, 1975, Library of Congress Catalog Card No. 74-81544.

"Private Line Interconnection - Voice Applications," Bell System Transmission Engineering Technical Reference (PUB 43201) 1974.

Appendix A. Status of HAR in the United States.

STATE	LOCATION	CURRENT STATUS	STATION[a] LICENSING	STATION TYPE CABLE	STATION TYPE MONOPOLE	FREQUENCY 530 kHz	FREQUENCY 1610 kHz	TYPES OF INFORMATION PROVIDED
Colorado	Dumont, I-70 Dillon, I-70	Removed	Experimental		X		X	Weather Advisory, Alternate Routing
Idaho	Elk City	Relocated	Experimental		X		X	Construction and Maintenance
New York	Lake Placid	Inactive	TIS (temp)		X		X	Olympic Parking and Routing
Pennsylvania	Walt Whitman	Removed	Experimental	X		X		Traffic Info. into Phil.
	U.S. 202	Inactive	Part 15	X		X		Traffic Info. into Phil.
	I-95 South		Part 15	X		X		Traffic Info. into Delaware
	I-95 North		Part 15	X		X		Traffic Info. into New Jersey
	Schylkill Exp. (I-676)		Part 15	X		X		Traffic Info. into Phil.
Texas	Chambers County	To be	TIS		X		X	Construction and
	I-10 (2 Sta.)	Relocated			X		X	Maintenance
Wyoming	Walcott Junction, and Laramie on I-80	Inactive	Part 15	X		X		Weather Advisory
Virginia	Bells Rd. Int.	Relocated	TIS (temp)		X	X		Construction and Maintenance
	I-64/360 Int.				X	X		
	Belvidere St.				X	X		
	@ Toll Plaza				X	X		
	Downtown Expressway							
Arizona	Sky Harbor Int. Airport; Phoenix	Active	TIS		X		X	Airport Park and Routing
California	Los Angeles Int.	Active	Experimental	X		X		Airport Park and
	and Cacramento Metro Airports	Active			X	X		Routing
Florida	Sarasota-Mantee	Active	TIS		X		X	Airport Park and
	Tampa Int. Airports	Active	TIS		X	X		Routing
Kentucky	Cinn. Int. Airport (2 Stations) and	Active	TIS		X		X	Airport Park and Routing
	Louisville Standiford Airport	Active	TIS		X	X		
Massachusetts	Logan Airport	Active	TIS		X	X		Airport Park and Routing
Missouri	Kansas City Int. Airport	Active	TIS		X		X	Airport Park and Routing
Minnesota	Minn./St. Paul Int. Airport	Active	TIS		X	X		Airport Parking Lot Construction
Oklahoma	Tulsa Airport	Active	TIS		X	X		Airport Parking and Routing
Texas	Houston Int. Airport	Active	TIS		X		X	Airport Park and Routing
	Houston Hobby Airport	Active	TIS		X		X	Airport Park and Routing
Illinois	Upper and Lower Section of Edens Exp.	Active	TIS		X		X	Construction and Maintenance

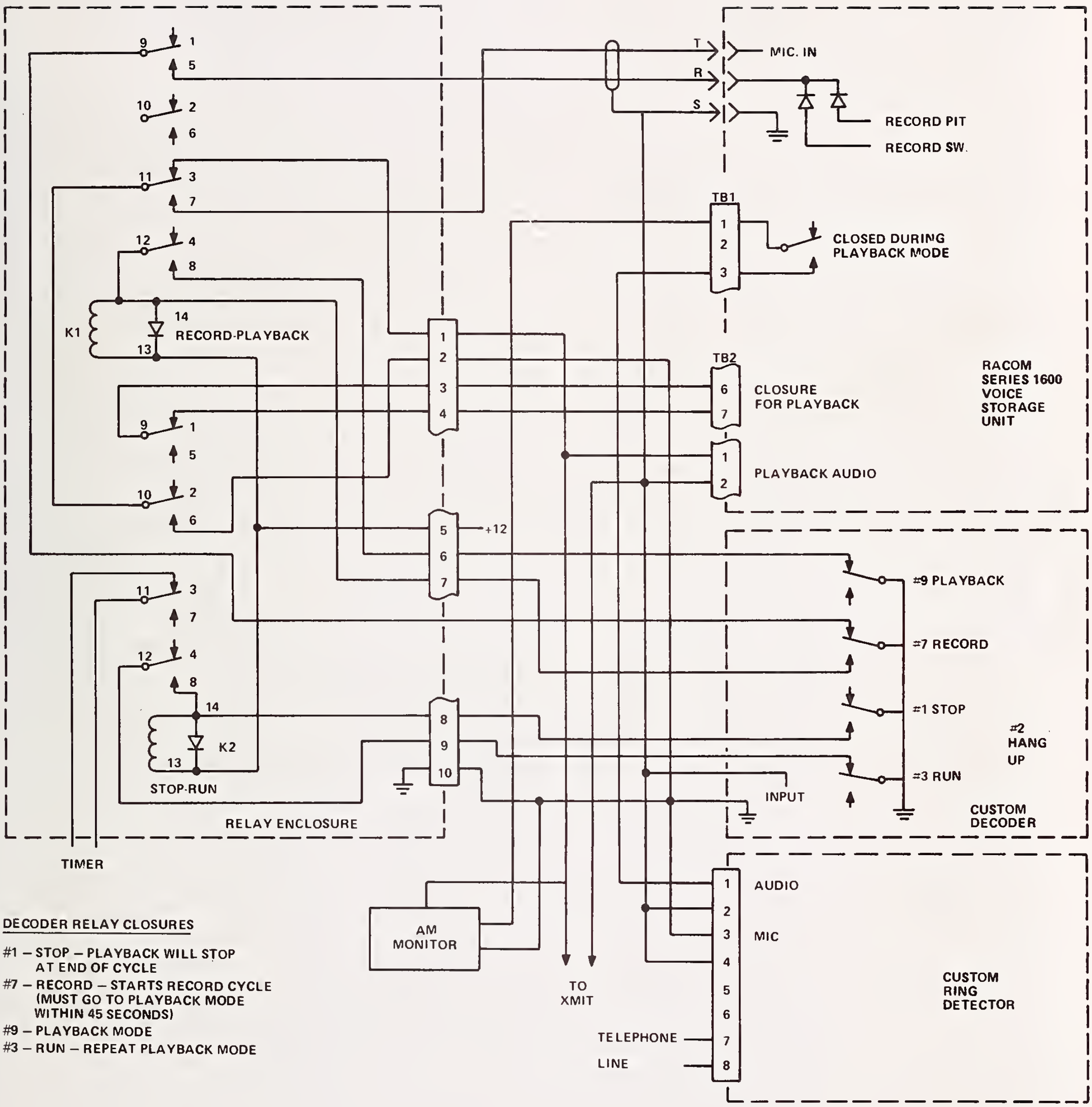
Appendix A. (Continued).

STATE	LOCATION	CURRENT STATUS	STATION[a] LICENSING	STATION TYPE CABLE	MONOPOLE	FREQUENCY 530 kHz	1610 kHz	TYPES OF INFORMATION PROVIDED
Ohio	I-75 in Hamilton County (Cinn. Area)	Active	TIS		X		X	Construction and Maintenance
	Columbus	Active	TIS		X	X		Unknown
Virginia	Fredricksburg Quantico, I-95 and Rt. 637	Active	TIS		X		X	Construction and Maintenance
	Hampton Roads Tunnel	Active	TIS		X	X		Traffic and Routing
Alabama	I-59, Steele	Active	TIS		X		X	Unknown
	U.S. 231 and I-59	Active	TIS		X		X	Unknown
Georgia	I-75 North and South approaches	Active	TIS		X	X		Traffic and Routing through Atlanta
Iowa	I-80, Walnut Junct. Rt. 301 and I-80	Active	Experimental		X		X	General Information, Construction and Maintenance
Minnesota	I-35W, Minn.	Active	TIS	X			X	Traffic and Routing Info.
Oklahoma	Turley	Active	TIS		X		X	Unknown
Tennessee	Gatlinburg (5 stations)	Active	TIS		X	X	X	Traffic and Routing
Washington	Snoqualmie Pass, I-90	Active	TIS		X		X	Weather Advisories
Washington, D.C.	Potomac River	Experimental	TIS		X	X		Boating Advisories
California	Los Angeles Airport	Planned	TIS		X	X		Expansion to Include Freeways
Michigan	Pontiac, Silverdome	Planned	TIS		X		X	Stadium Park and Routing
Minnesota	I-94 between Minneapolis and St. Paul	Planned	TIS		X		X	Construction and Maintenance
New Jersey	I-80 Reconstruction	Planned	TIS		X			Construction and Maintenance
New York	George Washington Bridge	Planned	TIS	X		X		Routing Information
	Long Island Corridor	Planned	TIS	X	X			Traffic, Routing, Hazards (IMIS Project)
Nevada	Las Vegas Airport	Planned	TIS		X			Airport Park and Routing
Tennessee	Knoxville	Planned	TIS		X		X	Construction and Maintenance

Appendix A. (Concluded).

STATE	LOCATION	CURRENT STATUS	STATION[a] LICENSING	STATION TYPE		FREQUENCY		TYPES OF INFORMATION PROVIDED
				CABLE	MONOPOLE	530 kHz	1610 kHz	
Texas	Dallas—Ft. Worth Int. Airport	Planned	TIS		X		X	Airport Park and Routing
Wisconsin	Milwalkee Airport	Planned	TIS		X			Airport Park and Routing
West Virginia	I-77 Charleston to Beckley (4 stations)	Planned	TIS		X		X	Construction and Maintenance
Virginia	I-95 and U.S. 30 I-95 and Rt. 207 I-95 and U.S. 50	Planned	TIS		X	X	X	Construction and Maintenance

[a]Stations noted as "Part 15" are not licensed. Performance of such stations is inferior to licensed TIS's.



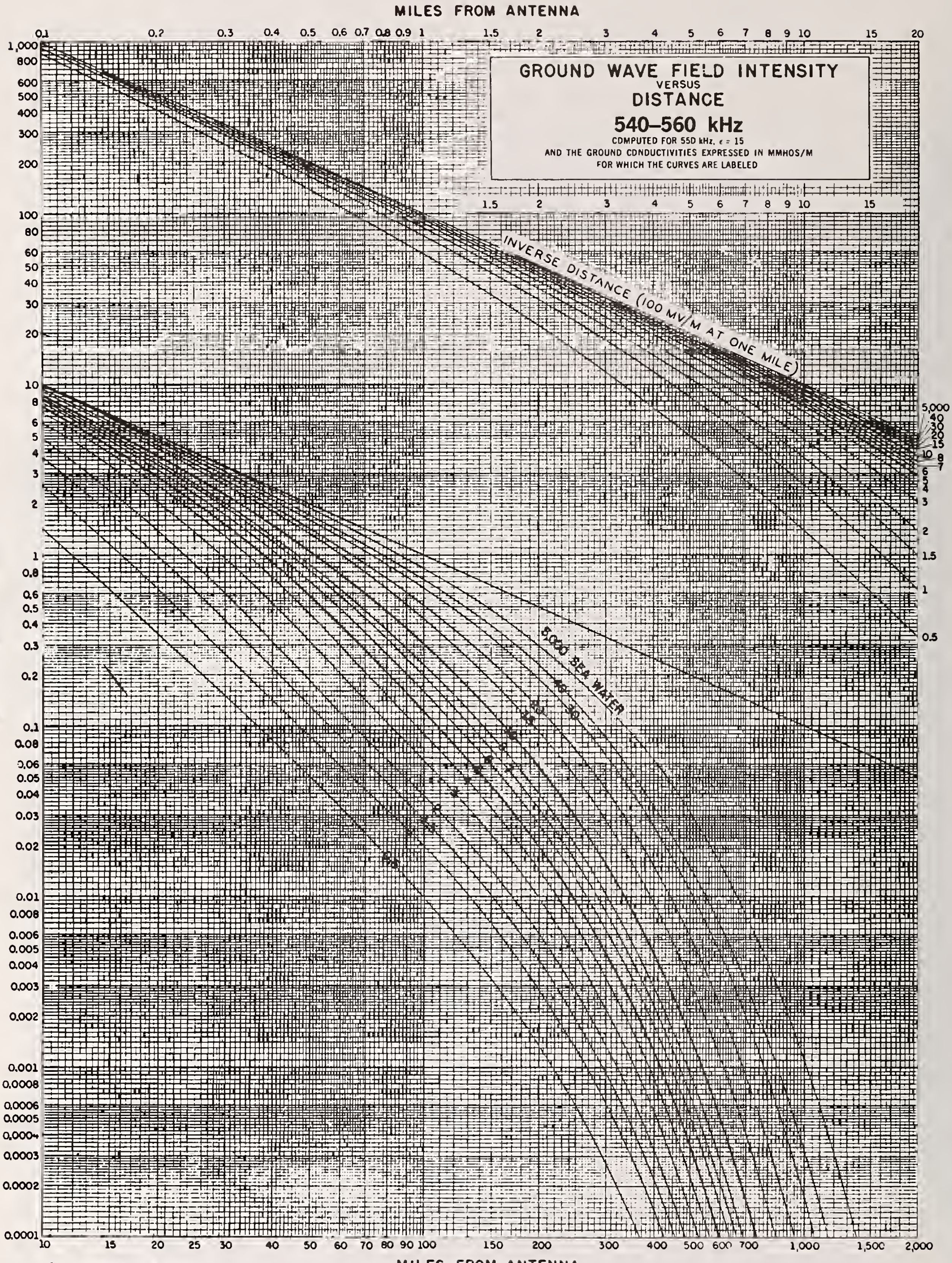
DECODER RELAY CLOSURES

#1 – STOP – PLAYBACK WILL STOP AT END OF CYCLE
#7 – RECORD – STARTS RECORD CYCLE (MUST GO TO PLAYBACK MODE WITHIN 45 SECONDS)
#9 – PLAYBACK MODE
#3 – RUN – REPEAT PLAYBACK MODE

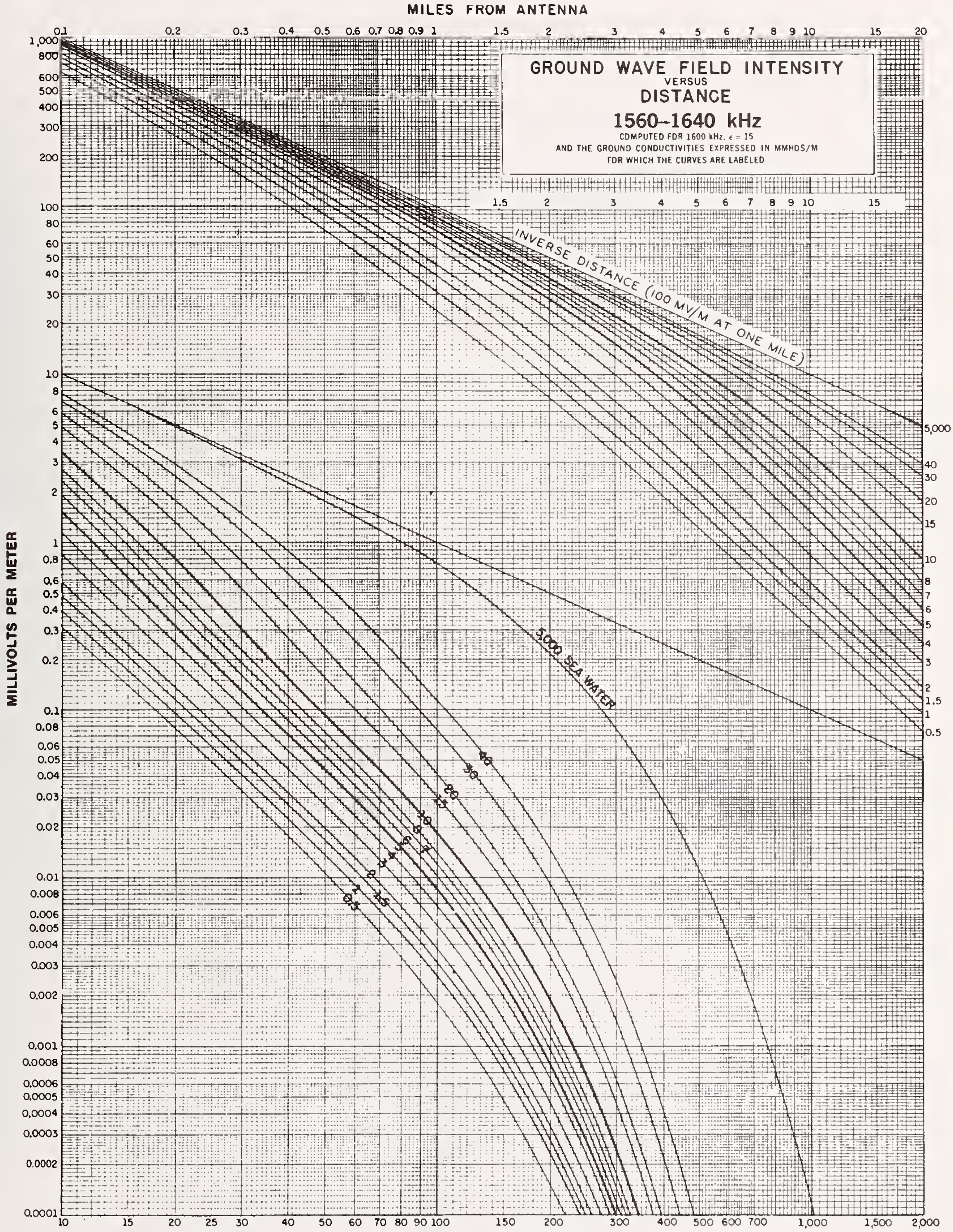
HAR Voice Storage Recorder Control, Davenport, Iowa.

Appendix C

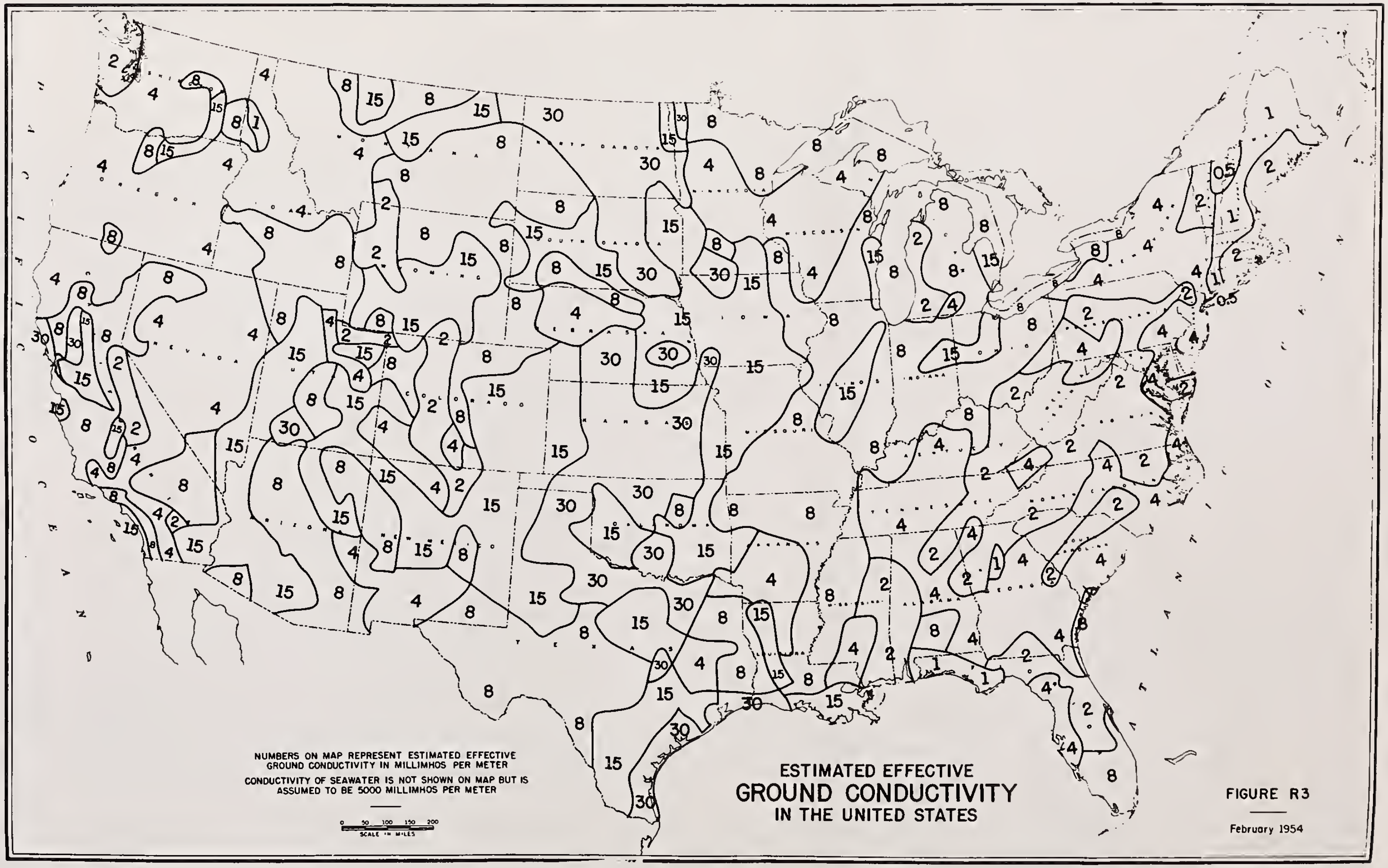
Propagation Curves from Part 73, FCC Rules and Regulations.



FCC § 73.184, GRAPH 1



FCC § 73.184, GRAPH 19A



ESTIMATED EFFECTIVE
GROUND CONDUCTIVITY
IN THE UNITED STATES

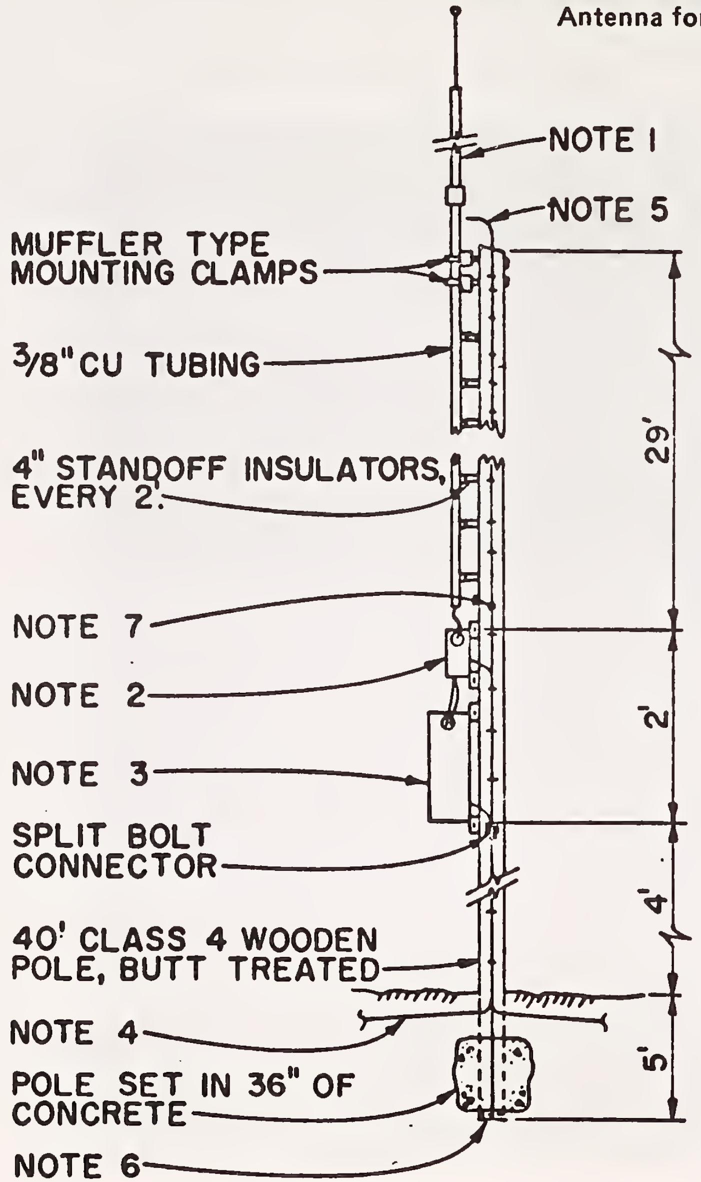
FIGURE R3

February 1954

FCC § 73.190 FIGURE R3

Appendix D.

U. S. Park Service Recommended Installation of Morad SF 530
Antenna for Maximum Radio Coverage



NOTES:

1. 530 kHz ANTENNA WITH LOADING COIL AND TUNING STUB. LATTER MUST BE ADJUSTED BY INSTALLING ENGINEER.

2. TRANSMITTER UNIT (SECURITY BOX ACCESSIBLE ONLY TO FCC LICENSED PERSONNEL).

3. TAPE PLAYER AND TRANSMITTER POWER SUPPLY (SECURITY BOX ACCESSIBLE TO PARK PERSONNEL).

4. INSTALL COUNTERPOISE CONSISTING OF EIGHT 100' EQUALLY-SPACED RADIALS OF NO. 12 (MIN) BARE COPPER WIRE BURIED 18" WHERE POSSIBLE (6" MIN. OR TO SOLID ROCK). SOLDER ALL RADIALS TO NO. 6 COPPER GROUND WIRE. EXTEND ONE RADIAL TO ALL WATER LINES, METAL FENCES, POWER SYSTEM GROUNDS AND FUEL TANKS LYING LESS THAN 400' FROM POLE.

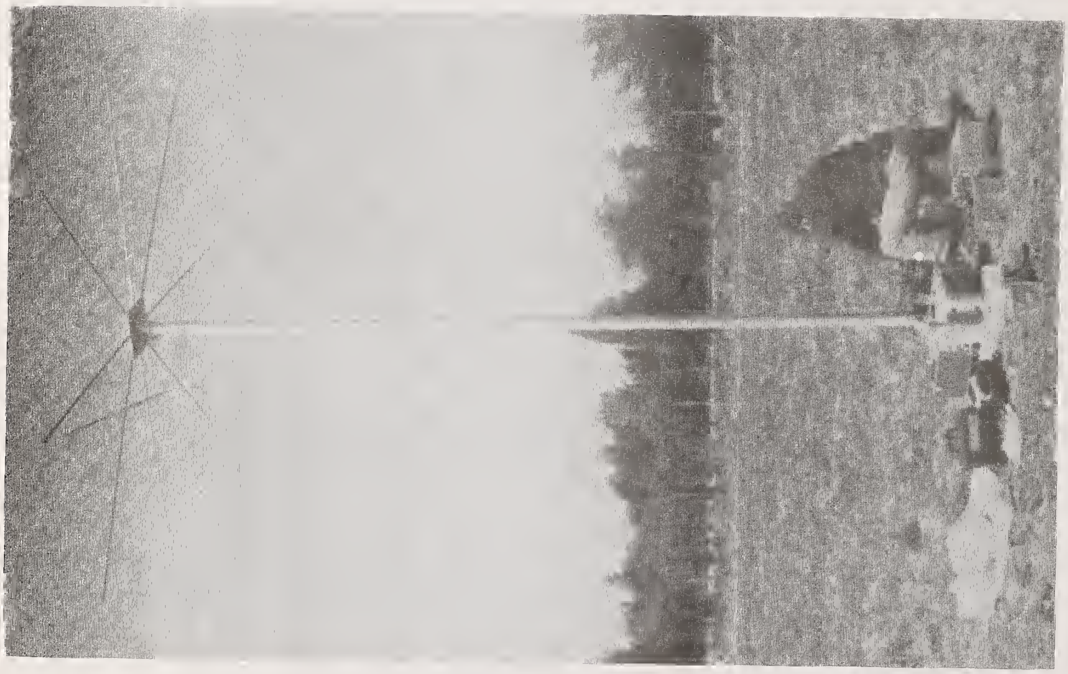
5. BEND 1/2" X 6' COPPERWELD GROUND ROD WITH 6" RADIUS TO FORM LIGHTNING GAP. POINTED TIP SHALL BE 1/4" FROM ANTENNA. FASTEN TO POLE AND CONNECT TO NO. 6 BARE COPPER GROUND WIRE BONDED TO CABINETS AND GROUND RADIALS RUNNING TO POLE BUTT. STAPLE GROUND WIRE TO POLE EVERY 2'.

6. SPIRAL 4' LENGTH OF NO. 6 BARE COPPER WIRE AND STAPLE TO BUTT END OF POLE.

7. FORM 1/8" GAP IN GROUND WIRE ON SIDE OF POLE WHERE INDICATED.

8. THE FOLLOWING METRIC CONVERSIONS APPLY:

1 ft. = 0.30 m
1 in. = 25.4 mm



Monopole with Capacitive Top Loading

Helically Wound Monopole

Experimental Monopoles.

Appendix F

Calculated Helical Antenna Design Parameters.

OPERATING FREQUENCY (KHZ)	AXIAL HEIGHT (FEET)	ANTENNA DIAMETER (INCHES)	WIRE GUAGE (AWG)	WIRE LENGTH (FEET)	NO.OF TURNS /FOOT	TURN SPACING (INCHES)	WIRE PER FOOT	ANTENNA EFF. PERCENT	TAD DEV (%)	
530.0	5.0	2.00	14	1145.50	437.5	.027	229.1	.07	0.0	TAP POINT = 0 FEET, 7.60 INCHES
530.0	10.0	2.00	14	1315.83	251.3	.048	131.6	.24	0.0	TAP POINT = 1 FEET, 3.83 INCHES
530.0	15.0	2.00	14	1426.98	181.7	.066	95.1	.49	0.0	TAP POINT = 2 FEET, .64 INCHES
530.0	20.0	2.00	14	1511.49	144.3	.083	75.6	.82	0.0	TAP POINT = 2 FEET, 9.90 INCHES
530.0	25.0	2.00	14	1580.47	120.7	.099	63.2	1.23	0.0	TAP POINT = 3 FEET, 7.54 INCHES
530.0	30.0	2.00	14	1639.17	104.4	.115	54.6	1.70	0.0	TAP POINT = 4 FEET, 5.54 INCHES
530.0	35.0	2.00	14	1690.49	92.2	.130	48.3	2.23	0.0	TAP POINT = 5 FEET, 3.86 INCHES
530.0	40.0	2.00	14	1736.25	82.9	.145	43.4	2.81	0.0	TAP POINT = 6 FEET, 2.50 INCHES
530.0	45.0	2.00	14	1777.63	75.4	.159	39.5	3.45	0.0	TAP POINT = 7 FEET, 1.44 INCHES
530.0	50.0	2.00	14	1815.49	69.3	.173	36.3	4.15	0.0	TAP POINT = 8 FEET, .68 INCHES

ENGLISH TO METRIC CONVERSIONS:

1 ft = 0.30 m
1 in = 2.54 cm

OPERATING FREQUENCY (KHZ)	AXIAL HEIGHT (FEET)	ANTENNA DIAMETER (INCHES)	WIRE GUAGE (AWG)	WIRE LENGTH (FEET)	NO.OF TURNS /FOOT	TURN SPACING (INCHES)	WIRE PER FOOT	ANTENNA EFF. PERCENT	TAD DEV (%)	
530.0	5.0	3.00	14	1056.27	269.0	.045	211.3	.07	0.0	TAP POINT = 0 FEET, 7.53 INCHES
530.0	10.0	3.00	14	1213.34	154.5	.078	121.3	.26	0.0	TAP POINT = 1 FEET, 3.41 INCHES
530.0	15.0	3.00	14	1315.83	111.7	.107	87.7	.53	0.0	TAP POINT = 1 FEET,11.78 INCHES
530.0	20.0	3.00	14	1393.76	88.7	.135	69.7	.89	0.0	TAP POINT = 2 FEET, 8.56 INCHES
530.0	25.0	3.00	14	1457.37	74.2	.162	58.3	1.33	0.0	TAP POINT = 3 FEET, 5.68 INCHES
530.0	30.0	3.00	14	1511.49	64.1	.187	50.4	1.84	0.0	TAP POINT = 4 FEET, 3.12 INCHES
530.0	35.0	3.00	14	1558.82	56.7	.212	44.5	2.41	0.0	TAP POINT = 5 FEET, .86 INCHES
530.0	40.0	3.00	14	1601.01	51.0	.235	40.0	3.04	0.0	TAP POINT = 5 FEET,10.88 INCHES
530.0	45.0	3.00	14	1639.17	46.4	.259	36.4	3.74	0.0	TAP POINT = 6 FEET, 9.19 INCHES
530.0	50.0	3.00	14	1674.08	42.6	.281	33.5	4.48	0.0	TAP POINT = 7 FEET, 7.78 INCHES

ENGLISH TO METRIC CONVERSIONS:

1 ft = 0.30 m
1 in = 2.54 cm

OPERATING FREQUENCY (KHZ)	AXIAL HEIGHT (FEET)	ANTENNA DIAMETER (INCHES)	WIRE GUAGE (AWG)	WIRE LENGTH (FEET)	NO.OF TURNS /FOOT	TURN SPACING (INCHES)	WIRE PER FOOT	ANTENNA EFF. PERCENT	TAD DEV (%)	
530.0	5.0	4.00	14	997.21	190.5	.063	199.4	.08	0.0	TAP POINT = 0 FEET, 7.55 INCHES
530.0	10.0	4.00	14	1145.50	109.4	.110	114.5	.27	0.0	TAP POINT = 1 FEET, 3.21 INCHES
530.0	15.0	4.00	14	1242.26	79.1	.152	82.8	.57	0.0	TAP POINT = 1 FEET,11.31 INCHES
530.0	20.0	4.00	14	1315.83	62.8	.191	65.8	.95	0.0	TAP POINT = 2 FEET, 7.78 INCHES
530.0	25.0	4.00	14	1375.88	52.6	.228	55.0	1.41	0.0	TAP POINT = 3 FEET, 4.57 INCHES
530.0	30.0	4.00	14	1426.98	45.4	.264	47.6	1.94	0.0	TAP POINT = 4 FEET, 1.66 INCHES
530.0	35.0	4.00	14	1471.66	40.2	.299	42.0	2.55	0.0	TAP POINT = 4 FEET,11.02 INCHES
530.0	40.0	4.00	14	1511.49	36.1	.333	37.8	3.22	0.0	TAP POINT = 5 FEET, 8.66 INCHES
530.0	45.0	4.00	14	1547.52	32.8	.365	34.4	3.95	0.0	TAP POINT = 6 FEET, 6.57 INCHES
530.0	50.0	4.00	14	1580.47	30.2	.398	31.6	4.73	0.0	TAP POINT = 7 FEET, 4.74 INCHES

ENGLISH TO METRIC CONVERSIONS:

1 ft - 0.30 m
1 in = 2.54 cm

OPERATING FREQUENCY (KHZ)	AXIAL HEIGHT (FEET)	ANTENNA DIAMETER (INCHES)	WIRE GUAGE (AWG)	WIRE LENGTH (FEET)	NO.OF TURNS /FOOT	TURN SPACING (INCHES)	WIRE PER FOOT	ANTENNA EFF. PERCENT	TAD DEV (%)	
530.0	5.0	5.00	14	953.69	145.7	.082	190.7	.08	0.0	TAP POINT = 0 FEET, 7.61 INCHES
530.0	10.0	5.00	14	1095.50	83.7	.143	109.5	.29	0.0	TAP POINT = 1 FEET, 3.11 INCHES
530.0	15.0	5.00	14	1188.04	60.5	.198	79.2	.59	0.0	TAP POINT = 1 FEET,11.03 INCHES
530.0	20.0	5.00	14	1258.40	48.1	.250	62.9	.99	0.0	TAP POINT = 2 FEET, 7.28 INCHES
530.0	25.0	5.00	14	1315.83	40.2	.298	52.6	1.47	0.0	TAP POINT = 3 FEET, 3.84 INCHES
530.0	30.0	5.00	14	1364.70	34.8	.345	45.5	2.03	0.0	TAP POINT = 4 FEET, .67 INCHES
530.0	35.0	5.00	14	1407.42	30.7	.391	40.2	2.66	0.0	TAP POINT = 4 FEET, 9.77 INCHES
530.0	40.0	5.00	14	1445.52	27.6	.435	36.1	3.36	0.0	TAP POINT = 5 FEET, 7.14 INCHES
530.0	45.0	5.00	14	1479.97	25.1	.478	32.9	4.12	0.0	TAP POINT = 6 FEET, 4.76 INCHES
530.0	50.0	5.00	14	1511.49	23.1	.520	30.2	4.94	0.0	TAP POINT = 7 FEET, 2.63 INCHES

ENGLISH TO METRIC CONVERSIONS:

1 ft = 0.30 m
1 in = 2.54 cm

OPERATING FREQUENCY (KHZ)	AXIAL HEIGHT (FEET)	ANTENNA DIAMETER (INCHES)	WIRE GUAGE (AWG)	WIRE LENGTH (FEET)	NO.OF TURNS /FOOT	TURN SPACING (INCHES)	WIRE PER FOOT	ANTENNA EFF. PERCENT	TAD DEV (%)	
530.0	5.0	6.00	14	919.54	117.1	.102	183.9	.09	0.0	TAP POINT = 0 FEET, 7.70 INCHES
530.0	10.0	6.00	14	1056.27	67.2	.178	105.6	.30	0.0	TAP POINT = 1 FEET, 3.08 INCHES
530.0	15.0	6.00	14	1145.50	48.6	.247	76.4	.61	0.0	TAP POINT = 1 FEET,10.85 INCHES
530.0	20.0	6.00	14	1213.34	38.6	.311	60.7	1.02	0.0	TAP POINT = 2 FEET, 6.94 INCHES
530.0	25.0	6.00	14	1268.71	32.3	.371	50.7	1.52	0.0	TAP POINT = 3 FEET, 3.32 INCHES
530.0	30.0	6.00	14	1315.83	27.9	.430	43.9	2.10	0.0	TAP POINT = 3 FEET,11.96 INCHES
530.0	35.0	6.00	14	1357.03	24.7	.486	38.8	2.76	0.0	TAP POINT = 4 FEET, 8.87 INCHES
530.0	40.0	6.00	14	1393.76	22.2	.541	34.8	3.48	0.0	TAP POINT = 5 FEET, 6.02 INCHES
530.0	45.0	6.00	14	1426.98	20.2	.594	31.7	4.27	0.0	TAP POINT = 6 FEET, 3.42 INCHES
530.0	50.0	6.00	14	1457.37	18.6	.647	29.1	5.11	0.0	TAP POINT = 7 FEET, 1.07 INCHES

ENGLISH TO METRIC CONVERSIONS:

1 ft = 0.30 m
1 in = 2.54 cm

APPENDIX G — RECORDERS FOR HAR USE.

Table G-1. NAB Cartridge Type Recorder/Players.

Manufacturer	Model Number	Frequency Response	Wow and Flutter	Signal-To-Noise Ratio[a]	Distortion[b]	Output Impedance	Audio Output	Input Voltage	Input Power	Comments
Broadcast Electronics, Inc. (Spotmaster)	Series 2100	±2 dB from 50 Hz to 15 kHz	0.2% RMS (unweighted) 0.15% peak (weighted)	62 dB	2% or less record to playback	600 ohms balanced	+8 dBm, +20 dBm peak before clipping	105 to 125 210 to 230 VAC	40W	
Broadcast Electronics, Inc. (Spotmaster)	Series 3000	±2 dB from 50 Hz to 15 kHz	0.2% RMS (unweighted) 0.15% peak (weighted)	62 dB	2% or less record to playback	600 ohms balanced	+8 dBm, +20 dBm peak before clipping	105 to 125 210 to 230 VAC	50W	
Broadcast Electronics, Inc. (Spotmaster)	Model 5300B	±2 dB from 50 Hz to 15 kHz	0.2% RMS (unweighted) 0.15% peak (weighted)	62 dB	2% or less record to playback	600 ohms balanced	+8 dBm, +20 dBm peak before clipping	105 to 125 210 to 230 VAC	120W	3 deck playback
Broadcast Electronics, Inc. (Spotmaster)	Model 5500	±2 dB from 50 Hz to 15 kHz	0.2% RMS (unweighted) 0.15% peak (weighted)	62 dB	2% or less record to playback	600 ohms balanced	+8 dBm, +20 dBm peak before clipping	105 to 125 210 to 230 VAC	120W	5 deck playback
Broadcast Electronics, Inc. (Spotmaster)	Models 605C/610CR	±2 dB from 50 Hz to 12 kHz	0.2% or less RMS	45 dB at 160 nWb/m 1 kHz ref.	2% or less at normal recording level	600 ohms. 150 ohm output optional	+4 dBm, +12 dBm peak	108 to 125 VAC	75W 605, 150W 610	5/10 deck playback, 95, 25 mm/s tape speed available.
Broadcast Electronics, Inc. (Spotmaster)	Series 2000	±2 dB from 50 Hz to 15 kHz	0.2% RMS (unweighted) 0.15% peak (weighted)	62 dB	2% or less at +16 dBm output	600 ohms balanced	+8 dBm, +16 dBm peak before clipping	105 to 125 210 to 230 VAC	45W	
Broadcast Electronics, Inc. (Spotmaster)	Series 500	±2 dB from 50 Hz to 12 kHz	0.2% RMS (unweighted) 0.15% peak (weighted)	52 dB Ref. 160 nWb/m at 1 kHz	2% or less record to playback	600 ohms balanced	+4 dBm, +14 dBm peak	105 to 125 VAC	50W	
Broadcast Electronics, Inc. (Spotmaster)	MiniSeries 305D	±2 dB from 50 Hz to 15 kHz	0.2% RMS (unweighted) 0.15% peak (weighted)	55 dB	1.5% or less at 0 VU, 400 Hz reference	600/150 ohms	+8 dBm, +18 dBm peak	105 to 125 VAC	75W	Tape speed available.
Tapecaster	X700-P	±2 dB from 50 Hz to 12 kHz	0.2% or less	55 dB or better	2% or less	600 ohms	0 dBm	105 to 125 VAC	50 W	Play only. Model X700-RP has identical specifications, but also records.
Telex	TMM 150	±4 dB from 50 Hz to 8000 Hz	0.35% RMS or less (unweighted)	48 dB			Low impedance output, 1V preamp output	115 VAC	100 W maximum	
	MC-Series	±1 dB, from 50 Hz to 15 kHz	0.12% peak (weighted) or less	53 dB, Ref 160 nWb/m, 1 kHz	2% or less Record/Play.	600 or 150 ohm	20 dBm	117 VAC	35W	Speed is adjustable, fast wind, recording capabilities.
Track Audio, Inc. (Sonifex)	D-PAC-M	50 Hz to 12 kHz ±2 dB	0.15% or less (unweighted)	56 dB	2% max total harmonic, ref 8 dBm output	600 ohms balanced	0 dBm	110 VAC	N/A	Model D-PAC-R is also available with record capabilities
	S 5000	40 Hz to 15 kHz ±2 dB	0.15% RMS or less	62 dB	2% max, ref +8 dBm	600 ohms unbalanced	0 dBm	110 VAC	N/A	Speed is variable +50% to -30%
Travelers Information Service, Inc.	34-368					5000 ohms unbalanced	500 mV AC (RMS)	12 VDC	1.8 W	Tape deck only. No electronics
International Tapetronics Corporation	SP Series	±2 dB from 50 Hz to 15 kHz	0.2% RMS or less (unweighted)	55 dB	2% or less record to playback at 0 VU record level	600/150 ohms balanced	15 dBm, +15 dBm before clipping	117 VAC	70 W	Other tape speeds and +18 dBm audio output available on special order
	WP Series	±2 dB from 50 Hz to 15 kHz	0.2% RMS or less (unweighted)	55 dB	2% or less record to playback at 0 VU record level	600/150 ohms balanced	15 dBm, +15 dBm before clipping	117 VAC	70 W	Other tape speeds and +18 dBm audio output available on special order
	RP Series	±2 dB from 50 Hz to 15 kHz	0.2% RMS or less (unweighted)	55 dB	2% or less record to playback at 0 VU record level	600/150 ohms balanced	+5 dBm, +15 dBm before clipping	117 VAC	77 W	Other tape speeds and +18 dBm audio output available on special order
	3D Series	±2 dB from 50 Hz to 15 kHz	0.2% RMS or less (unweighted)	55 dB	2% or less record to playback at 0 Vu record level	600/150 ohms balanced	+5 dBm, +15 dBm before clipping	117 VAC	144W	Other tape speeds and +18 dBm audio output available on special order
	PD II Series	±2 dB from 50 Hz to 12 kHz	0.2% or less (weighted)	52 dB	2% or less record to playback at 0 VU record level	600 ohms balanced	+5 dBm, +15 dBm before clipping	117 VAC	70 W	Other tape speeds and +18 dBm audio output available on special order

[a] Unless otherwise noted, signal-to-noise given for 400 Hz reference at 3% total harmonic distortion (THD).

[b] Unless otherwise noted, distortion given for 1 kHz reference at 160 nanowebers/meter (nWb/m) tape magnetization.

Table G-1. (Continued).

Manufacturer	Model Number	Frequency Response	Wow and Flutter	Signal to Noise Ratio	Distortion	Output Impedance	Audio Output	Input Voltage	Input Power	Comments
Audi-Cord	100 Series	± 2 dBm from 50 Hz to 15 kHz	0.15% peak or less (weighted)	48 dB 160 nWb/m at 1 kHz Ref.	0.5% max total harmonic at +18 dBm	600/150 ohms balanced	+8 dBm, +20 dBm clipping	117 VAC	N/A	Player-recorder available
	A series	± 2 dB to NAB standard tape specs	0.15%, weighted, max	47 dB 160 nWb/m at 1 kHz Ref.	0.5% max total harmonic at +18 dBm	600/150 ohms balanced	+8 dBm, +20 dBm clipping	117 VAC	50 VA	Player-recorder available
Ampro Broadcasting	Series CT 2500	± 2 dBm from 50 Hz to 15 kHz	0.15% peak (weighted)	58 dB	3% max record to reproduce at 8 dB above NAB standard reference level, 400 Hz	600/150 ohms balanced	+10 dBm, +20 dBm before clipping	117/234 VAC	80 VA	
	Series CT 3500	± 2 dBm from 50 Hz to 15 kHz	0.15% peak (weighted)	58 dB	3% max record to reproduce at 8 dB above NAB standard reference level, 400 Hz	600/150 ohms balanced	+10 dBm, +20 dBm before clipping	117/234 VAC	80 VA	
	Series CT 4500	± 2 dBm from 50 Hz to 15 kHz	0.15% peak (weighted)	58 dB	3% max record to reproduce at 8 dB above NAB standard reference level, 400 Hz	600/150 ohms balanced	+10 dBm, +20 dBm before clipping	117/234 VAC	80 VA	
	Series CT 4500	± 2 dBm from 50 Hz to 15 kHz	0.15% peak (weighted)	58 dB	3% max record to reproduce at 8 dB above NAB standard reference level, 400 Hz	600/150 ohms balanced	+10 dBm, +20 dBm before clipping	117/234 VAC	80 VA	
	Series CT 5500	± 2 dBm from 50 Hz to 15 kHz	0.15% peak (weighted)	58 dB	3% max record to reproduce at 8 dB above NAB standard reference level, 400 Hz	600/150 ohms balenced	+10 dBm, +20 dBm before clipping	117/234 VAC	80 VA	3 deck playback
Harris Corporation (Criterion)	90-1	+3/-2 dB from 50 to 300 Hz; ± 2 dB from 300 Hz to 16 kHz	0.15% or better (unweighted)	53 dB at 160 nW/m at 1 kHz	Less than 1.5%	600/150 ohms balanced	+18 dBm	117 VAC	70 W	
	90-2	+3/-2 dB from 50 to 300 Hz, ± 2 dB from 300 Hz to 16 kHz	0.15% or better (unweighted)	53 dB at 160 nW/m at 1 kHz	Less than 1.5%	600/150 ohms balanced	+18 dBm	117 VAC	70 W	
	90-3	+3/-2 dB from 50 to 300 Hz; ± 2 dB from 300 Hz to 16 kHz	0.2% RMS or better (unweighted)	53 dB at 160 nW/m at 1 kHz	Less than 2%	600/150 ohms balanced	+18 dBm	117 VAC	70 W	
RCA	RT-125A RT-126A RT-127A	50 Hz to 15,000 Hz ±2 dB	0.2% RMS (unweighted)	62 dB	2% or less	600 ohms balanced	+8 dBm	105 to 125 VAC	–	RT-125A - Play only. Others available play or play-record.

Table G-2. Non-NAB Type Recorders.

Manufacturer	Model No. (Typical Basic Model)	Frequency Response	Wow and Flutter	Signal-to-Noise (w/o noise comp.)	Distortion (THD)	Output Impedance	Audio Output (into Hi-Z)	Comments
EDCO Products	CA-77b	20 Hz - 10 kHz ± 2 dB	0.15% or less (weighted)	42 dB	1% or less at 400 Hz	600 ohms balanced, 150 ohms unbalanced	+4 dBm balanced, -2 dBm unbalanced	Variable speed, Broadcast Cassette Recorder
Audio Sine	AS-187 R/P	100 Hz - 5000 Hz ± 3 dB	0.3% or less	40 dB	—	8-16 ohms	2 W	Uses standard 8-track cartridge

Table G-3. Solid-State Memory Recorder/Players.

Manufacturer	Model No.	Frequency Response	Signal-to-Noise	Output Impedance	Audio Output	Maximum Duration of Recording	Input Voltage	Input Power
Audichron Co.	HDQ 220	–	–	1 ohm, 600 ohms or 900 ohms		–	–	–48 VDC at 200 milliamps
Wang Voice Communications, Inc.	Vocalizer 1000	100 Hz to 2,500 Hz ±3 dB	35 dB	600 ohms	20 dBm	16 seconds	117 VAC	10 VA
	VSU/500R	–	–	600 ohms	20 dBm	16 seconds	+/–12 VDC –5 VDC	3 VA
	VSU/650R	–	–	600 ohms	20 dBm	48 seconds	+/–12 VDC +5 VDC	3 VA
Racom	Series 1600	300 Hz to 2500 Hz ±3 dB	–	10,000 ohms or 600 ohms (both balanced)	0.06 VAC at 10 Kr +5 dBm at 600 ohms	20 seconds	120 VAC	30 W

HAR Advance Visual Signing Options

* INCREASE SPACING 100%.

SIGN	DIMENSIONS (INCHES)									
	A	B	C	D	E	F	G	H	J	K
STD.	84	42	1½	7	6E	5	16	32	3	8 E(M)
EXPWY.	108	54	2	9	8E	6	22	42	4	12 E(M)
FWY.	132	66	2	11	10E	7	28	53	5	15 E(M)

COLORS

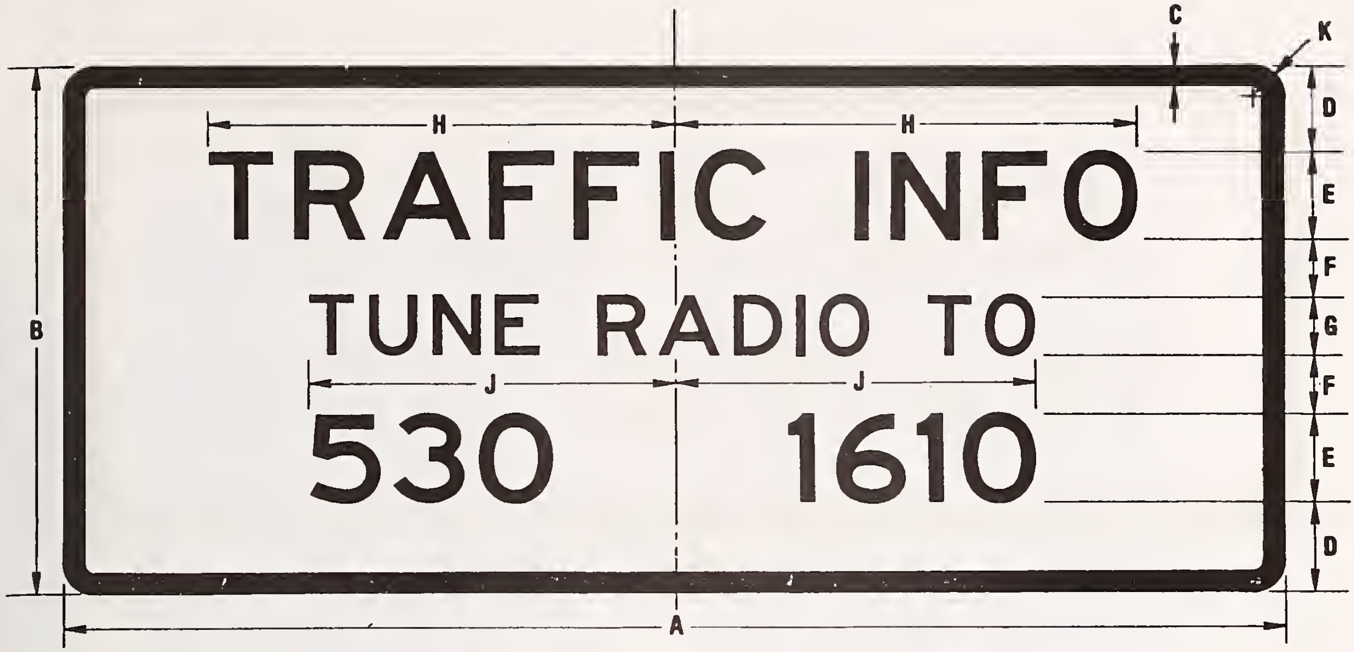
STANDARD COLOR COMBINATIONS FOR THE SIGN PANELS WILL DEPEND ON THE INTENDED USE, AS FOLLOWS:

1. LEGEND —BLACK (NON-REFL.)—WHERE THE HAR IS INTENDED TO
   BACKGROUND—YELLOW (REFL.) AUGMENT WARNING SIGNS EXCLUSIVELY.

2. LEGEND —BLACK (NON-REFL.)—WHERE THE HAR IS INTENDED TO
   BACKGROUND—ORANGE (REFL.) AUGMENT CONSTRUCTION ZONE SIGNING EXCLUSIVELY.

3. LEGEND —WHITE (REFL.) —WHERE THE HAR WILL BE USED TO
   BACKGROUND—BLUE (REFL.) PROVIDE MOTORIST SERVICE INFORMATION OR FOR MULTIPURPOSE AT VARIOUS POINTS IN TIME.

Figure H-1. Advance Visual Sign Specification Format, Early Warning Position.



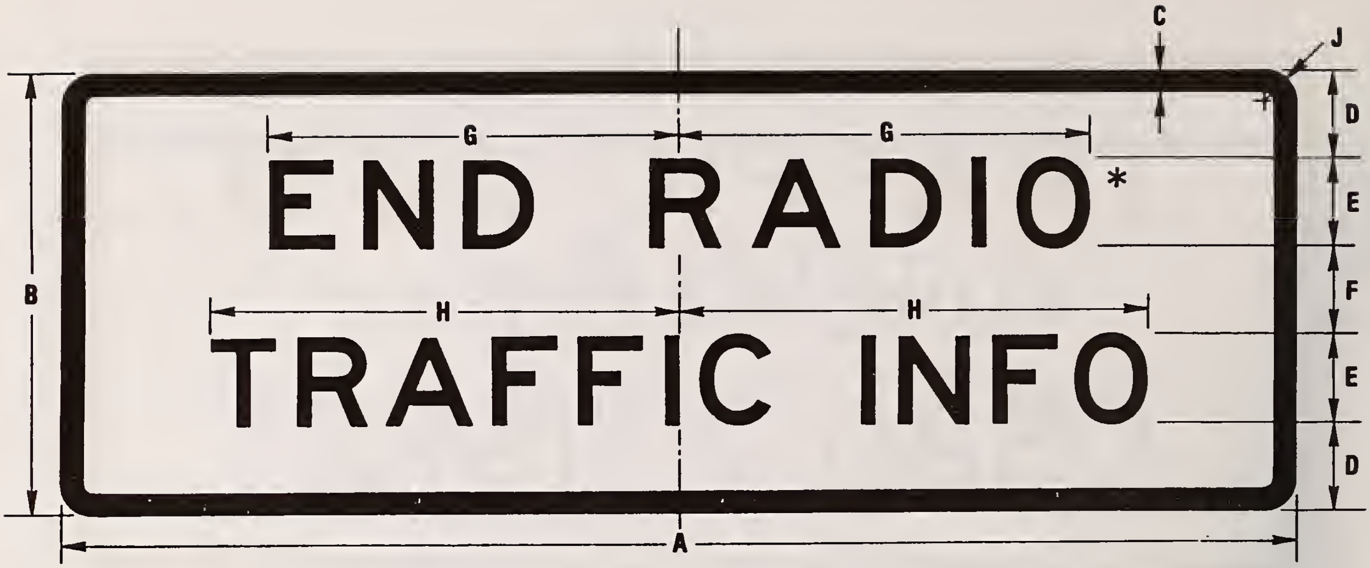
SIGN	DIMENSIONS (INCHES)									
	A	B	C	D	E	F	G	H	J	K
STD.	84	36	1½	6	6E	4	4E	32	25	3
EXPWY.	108	48	2	8	8E	5	6E	42	37	4
FWY.	132	60	2	10	10E	6	8E	53	49	5

COLORS

STANDARD COLOR COMBINATIONS FOR THE SIGN PANELS WILL DEPEND ON THE INTENDED USE, AS FOLLOWS:

1. LEGEND —BLACK (NON-REFL.)—WHERE THE HAR IS INTENDED TO AUGMENT WARNING SIGNS EXCLUSIVELY.
   BACKGROUND—YELLOW (REFL.)
2. LEGEND —BLACK (NON-REFL.)—WHERE THE HAR IS INTENDED TO AUGMENT CONSTRUCTION ZONE SIGNING EXCLUSIVELY.
   BACKGROUND—ORANGE (REFL.)
3. LEGEND —WHITE (REFL.) —WHERE THE HAR WILL BE USED TO PROVIDE MOTORIST SERVICE INFORMATION OR FOR MULTIPURPOSE AT VARIOUS POINTS IN TIME.
   BACKGROUND—BLUE (REFL.)

Figure H-2. Advance Visual Sign Specification Format, Active Area.



* INCREASE SPACING 100% FOR "RADIO."

SIGN	DIMENSIONS (INCHES)								
	A	B	C	D	E	F	G	H	J
STD.	84	30	1½	6	6E	6	28	32	3
EXPWY.	108	42	2	9	8E	8	37	42	4
FWY.	132	48	2	9	10E	10	46	53	5

COLORS

STANDARD COLOR COMBINATIONS FOR THE SIGN PANELS WILL DEPEND ON THE INTENDED USE, AS FOLLOWS:

1. LEGEND —BLACK (NON-REFL.)—WHERE THE HAR IS INTENDED TO
   BACKGROUND—YELLOW (REFL.) AUGMENT WARNING SIGNS EXCLUSIVELY.
2. LEGEND —BLACK (NON-REFL.)—WHERE THE HAR IS INTENDED TO
   BACKGROUND—ORANGE (REFL.) AUGMENT CONSTRUCTION ZONE SIGNING EXCLUSIVELY.
3. LEGEND —WHITE (REFL.) —WHERE THE HAR WILL BE USED TO
   BACKGROUND—BLUE (REFL.) PROVIDE MOTORIST SERVICE INFORMATION OR FOR MULTIPURPOSE AT VARIOUS POINTS IN TIME.

Figure H-3. Advance Visual Sign Specification Format, End Point.

a. Interchangeable On/Off Sign

c. Flashing Lights

b. Foldover Sign.

d. Flashing Light

Figure H-4. Methods of Indicating Station Status.

☆U.S. GOVERNMENT PRINTING OFFICE: 1981-341-428/1235

FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.